GUIDE FOR PREDICTING SEDIMENT YIELDS FROM FORESTED WATERSHEDS

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

NORTHERN REGION
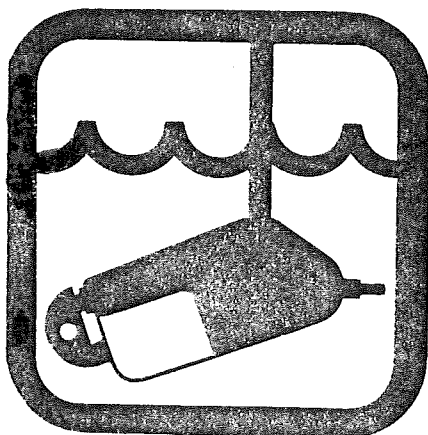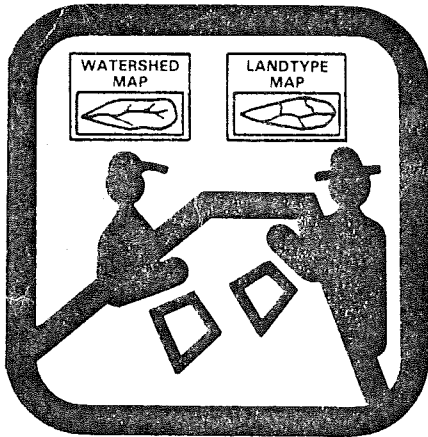**INTERMOUNTAIN REGION**
Soil and Water Management

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U.S. FOREST SERVICE
NORTHERN REGION
INTERMOUNTAIN REGION
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Prepared by a Work Group Comprised of Soil Scientists, Hydrologists, and
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A working draft of this document entitled "Guidelines for Predicting Sediment
Yields" was previously released in July 1980. This document is essentially
the same. Changes made are primarily editorial in nature to clarify and
further explain concepts and assumptions.

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EXECUTIVE SUMMARY

A sediment yield prediction procedure has been developed by a work group composed of soil scientists, hydrologists, and watershed specialists of the Northern Region, Intermountain Region, and the Intermountain Forest and Range Experiment Station. The procedure is applicable to the Northern and Intermountain Region's forested watersheds. The procedure was developed principally for watersheds in or generally associated with the Idaho Batholith but the process described has the capability of adaptation to other forested areas. Extrapolation of the numbers given in this guide to areas outside of the Idaho Batholith should be done with extreme care.

The model is applied on watersheds that are stratified using land systems inventory map units. The model produces quantified estimates of sediment yields prior to any management (natural sediment yield) and sediment yields in response to various management scenarios for any number of years. The types of management activities modeled are roading, logging, and fire. The model estimates on-site erosion for a given management activity modifies the amount of erosion according to general land unit characteristics, delivers the eroded material to the stream system, and routes it through the watershed to a critical stream reach where interpretations are made and where monitoring for achievement of planning objectives should take place.

The model simplifies, for analysis, an extremely complex physical system and is developed from a limited data base and scientific knowledge pool. Although it produces specific quantitative values for sediment yield, the results should be treated as rather broad estimates of how real systems may respond. The validity of this model is best when the results are used to compare alternatives, not for predicting specific quantities of sediment yielded. Values produced by this procedure are probably valid for comparisons only where large differences among alternatives are produced.

The model is a conceptual framework which outlines a process and is designed to be supplemented by local data and adapted by individual Forests to better reflect local conditions and observations. As a state-of-the-art effort to predict sediment yield, the procedure will undoubtedly receive close scrutiny. In most instances, better and more precise information and techniques applicable to the level of forest management, as practiced today, are simply not available at this time. Consequently, the procedure will undergo continual change and revision. As more information becomes available from studies such as the Silver and Horse Creek studies, this guide will be revised to incorporate any new data and information.

The authors recognize that every model is subject to misuse. Many models are probably misused because in many cases more appropriate models are not available. Users are often forced to use models outside the range of conditions considered during development simply because the user must have an answer. For this reason, the limitations and assumptions about the model are clearly documented. Users are encouraged to use their technical expertise considerable professional judgment to assure that reasonable use is made of this model. Models are simply tools to assist in decisionmaking, and users ought to test model results against their best technical judgment of what can logically be expected to actually occur on the ground.

INTRODUCTION

It is becoming increasingly apparent that a consistent method for predicting sediment yield from Forest lands, for use in land management planning, is urgently needed to respond to the requirements of the National Forest Management Act (NFMA). The method must reasonably predict changes in sediment yield over time in response to Forest management activities. It should be documentable, portray a consistent logic, and conform to current best estimates of sediment production from research data. It should not be a cut and dried procedure to be followed absolutely without regard to local conditions; however, it should describe, in a conceptual sense, the erosional and sediment-producing processes that actually occur on landscapes. This method provides a basic set of assumptions, procedures, and a quantitative starting point from which to develop locally applicable estimates of natural (undisturbed) sediment production characteristics and response to management activities on a variety of lands. As a state-of-the-art effort to predict sediment yield, the procedure will undergo continual change and revision as new information becomes available. This effort should be thought of as a first approximation attempt to quantify extremely complicated watershed systems.

The procedure considers both on-site erosion and downstream sediment yield. Uses of these estimates include, but are not limited to, evaluations of on-site productivity, sedimentation of downstream developments, sediment impacts upon fish habitat, and water quality conditions. Because the model relates the effects of land disturbing activities to downstream sediment yield, best management practices can be evaluated to protect water quality conditions.

OBJECTIVES

Specific objectives for the sediment yield model are:

    1. To provide a systematic tool to estimate the response of watershed systems with respect to erosion and sediment yields.

    2. To develop a process that is conceptually usable at the project level, as well as at the land management planning level.

    3. To develop a model capable of estimating sediment yields under natural conditions, present management, and proposed management alternatives.

    4. To route predicted sediment yields to a key reach in a watershed system.

STANDARDIZATION

National Forests in the Northern and Intermountain Regions have used a number of techniques to estimate sediment yields from forest lands. Although all of the efforts draw on a common research data base, considerable divergence exists in the procedures, units of measure, and types of erosion compared by the various Forests. This divergence tends to confuse Forest Service land

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managers, the public, and even confounds the specialists themselves in attempting to draw meaningful comparisons between two or more Forests, Regions, or areas. The primary goal of this model is to standardize the procedure for predicting sediment yield. A glossary of terms and definitions is included as Appendix A. Agreement has been reached among the Regions to standardize the following aspects of the sediment prediction procedure:

1. Any sediment yield analysis must be done on a watershed basis to be meaningful.

2. Land systems inventory will form the basic units for subdividing watersheds where sediment yield is to be predicted. It is assumed that these units are delineated to reflect predictable slope hydrology and erosional responses.

3. For comparative purposes in planning, erosion and sediment will be expressed as sediment delivered to a stream rather than expressing it as on-site erosion.

4. The standard unit of measure will be tons/square mile/year.

5. Sediment will be expressed as total sediment (bedload plus suspended).

6. Standardized outputs for planning will show sediment yield for three conditions: natural, present, and proposed (with and without various types of mitigation).

LIMITATIONS AND ASSUMPTIONS

Simplifying assumptions have been made in preparing this model. Such assumptions are necessary to address in a manageable manner the complex relationships involved since all possible combinations, factors, and contingencies cannot be covered. The model is intended to be a conceptual framework that attempts to account for the principal controlling variables in the erosion-sediment delivery-routing system in a fundamental way. Most of the data for the model are derived from Idaho Batholith watersheds (range of 0.1 to 2.5 square miles drainage area with an average area of 1.0 square mile). The model contains coefficients for extrapolation to other areas. Users are cautioned that extrapolaton should be done with care. It is intended that Forests adapt the model to local conditions and use local data as the basis for extrapolation wherever it is available. The importance of using better local data, and estimates, if available, in place of supplied values cannot be overemphasized.

Specific assumptions implicit in use of the sediment prediction model are as follows:

1. Sediment yield can be usefully displayed as an expected average annual event although it is subject to considerable variability from year to year and within any single year.

2. Model outputs are primarily intended to indicate trends and to compare management alternatives and secondarily to provide quantified estimates of sediment yield.

3. The variables necessary to drive the model are obtainable from the land systems inventory at the landtype level and equivalent water resource inventories. The land units inventoried must reflect predictable slope hydrology and erosional responses.

4. Slope sediment delivery is defined as the transport of a portion of the eroded material from its source area downslope to a first or higher order stream. For these purposes, a first order stream is defined as any channel with discernible bed and banks.

5. Natural sediment yields of undisturbed watershed systems are derived primarily from streambank erosion of material supplied by creep and mass erosion processes inherent to the system which are independent of surface erosion processes induced by management.

6. Sediment derived from surface erosion should be separated from mass erosion because of differences in sediment delivery.

7. Although the model is conceptually usable at the project level, use of the model at this level requires more refined data and some adaptation of techniques.

CONCEPTUAL BACKGROUND

Available research data which apply to sediment yield in Forest environments are limited. A variety of assumptions concerning parent materials, landscape characteristics, and applicability are required to use these data to estimate sediment yields. The approach taken here is to assume that measurements of sediment yield (measured instream for small watersheds) are the best available for conditions existing on National Forest System lands of the Northern and Intermountain Regions. This data set provides the starting point for the proposed model and the empirical foundation upon which its application rests.

Data which apply directly to field conditions existing in the Northern and Intermountain Regions come primarily from research conducted by W. F. Megahan (Megahan 1974 and 1975; Megahan and Kidd 1972; Megahan and Molitor 1975; Rice Rothacher and Megahan 1972; Platts and Megahan 1975). Supporting and comparative data have been published by Anderson (1975a and b) and Andre and Anderson (1961) for a variety of types of materials in northern California. This literature is useful for developing quantitative estimates of natural sediment yield as well as estimates of sediment yield due to management activities.

There are three alternatives for estimating natural sediment yield. One approach is to use the Universal Soil Loss Equation (USLE) as documented by Wischmeier and Smith (1978), Curtis and Darrach (1977), and Darrach and Curtis (1978). The USLE approach was rejected because most of the conditions required for the use of a surface erosion prediction equation are not applicable on forest lands. Most sediment in undisturbed forest

environments is the result of mass erosion processes. The primary objective of the procedure developed here is prediction of instream sediment resulting from land management activities. Site-specific erosion values, as calculated using USLE, are of minor importance in relation to this objective. Given the present supporting data base for USLE and limitations, it was considered inappropriate to use it as a primary source of quantified data for this application. This should not imply that USLE should not be used for calculation of on-site erosion for other applications. Wischmeier and Smith (1978) indicate that the best agreement with USLE occurs when it is applied to slopes of 3 to 18 percent having consistent cropping and management systems represented in the data base used for equation development. Large scale averaging of parameter values, a necessary part of this model is expected to substantially reduce USLE accuracy. This should not imply that many of the same principles considered important in the USLE model were not applied to the erosion portions of this model.

A second approach is to deal with sediment yield delivered to a key stream reach based on available sediment data. This approach provides a quantitative estimate of sediment yield but does not identify the differences in sediment produced by various land units within the watershed nor does it specifically designate the portion of the total sediment yield attributable to land disturbing activities. Because of this limitation, this approach was also rejected.

A third approach is to separate erosional and delivery processes and consider them individually for each land unit. This is the approach chosen for this model because it can be used to estimate sediment yield differences among land units and it can also be used to show sediment yield from alternative management strategies.

The model developed here is intended for forested, mountainous watersheds and does not adequately address erosional processes occurring on rangeland watersheds. USLE models are recommended for estimating on-site surface erosion on rangeland watersheds where overland flow is a significant hydrologic process. Soil erosion nomographs which appear in Tew (1973), Wischmeier et al. (1971), and Wischmeier and Smith (1978), should be helpful. The USLE was not designed to estimate sediment yield, so users taking this approach must estimate deposition and channel-type erosion by other means. The method developed by the Pacific Southwest Interagency Committee (1968) may be appropriate in arid and semi-arid regions as an alternative methodology for directly estimating sediment yield from rangeland watersheds.

The sediment yield model presented in this guide provides a procedure for estimating sediment yield from undisturbed natural watersheds and the additional sediment yield due to management activities. Management-induced sediment is the additional sediment above natural yields resulting from man's activities. It is analyzed separately from that which is derived due to surface erosion processes and that resulting from mass erosion. Natural sediment yield, management-induced sediment from surface erosion, and management-induced mass erosion are then summed to give total sediment yield for any watershed after applying appropriate sediment delivery and routing coefficients.

The sediment yield model operates on a watershed basis. The watershed of interest to planning is delineated and further subdivided by appropriate map units such as landtypes. Natural sediment yield is estimated for each land unit and summed for the entire watershed. The natural sediment yield is then routed to the critical reach, where interpretations are made. Manageme it-induced sediment is estimated for roads, fire, and logging. On-site erosion is calculated for each of these activities for each land unit and the eroded material delivered to the nearest channel. Sediment due to all management activities is summed and then routed to the critical reach. The sediment yield component due to management-induced mass erosion is also estimated where this is considered significant and routed to the critical reach.

At the critical reach, natural sediment and management-induced sediment (surface and mass erosion) are summed to given an estimate of total sediment yield. The entire analysis is repeated for various management strategies for any number of years so that the natural undisturbed, the present, and the sediment yield from proposed management alternatives can be displayed and compared.

The effects of land disturbing activities are determined as on-site erosion and then delivered to drainages based on slope sediment delivery characteristics of the land. Slope sediment delivery is assumed to be a constant value for any particular type of landscape. It is defined as the proportion of erosion produced in a landscape which is delivered downslope to a firsc or larger order stream channel. Once in the stream, sediment is routed downstream using an empirical relationship.

Little data is available for estimating slope sediment delivery and what is available is extrapolated from landslide studies (Megahan et al. 1978). Use of sediment delivery concepts are considered important because they provide a mechanism for portraying effects of land disturbing activities as affected by various landtypes and provides the mechanism for delivering sediment to stream channels.

Sediment delivered to streams must next be transported through the stream system to a critical reach where interpretation about the significance of sediment yield is made. There is at present limited capability for evaluating sediment transport. Existing sediment routing formulas are too complex and data intensive for application in Forest planning. Therefore, a more generalized procedure is used. This procedure is a modification of an empirical relation derived by Roehl (1962).

After routing to a critical reach, natural sediment yield and sediment from land disturbing activities are combined as total sediment yield and compared to evaluate management alternatives for the undisturbed natural, present, and proposed management situation. The critical stream reach is the point in the watershed where total sediment yield is assessed in terms of its effects on other resources or resurce values. The analysis can be carried out for any number of years of interest to planning.

Wherever possible, research information is used to generate sediment yield predictions. These sediment yield estimates, based on data for small watersheds, must be extrapolated to relatively larger areas in the planning

process. The effect of extrapolation on reliability is unknown. Although extrapolation results in decreased quantitative reliability, relative trend and difference comparisons remain valid.

PROCEDURE

The sediment yield model proposed here consists of four major parts: (1) natural sediment yield; (2) sediment from surface erosion; (3) sediment from mass erosion; and (4) routing of that sediment to critical stream reaches (Figure 1). Interpretations of model outputs are made at critical reaches to relate sediment yield to resource values.

1. Natural Sediment Yield.

An estimate of natural (undisturbed) sediment yield must be developed to provide a basis for comparison with management-induced sediment yield predictions. The best source of this information is actual long-term real data of sediment yield. Another possible source is data from similar or related watersheds. In most cases, specific measured data will not be available and estimates must be made.

A basic assumption is made that the source of natural sediment is primarily stream channel erosion of banks and stored sediment. The source of supply of this eroded material is assumed to be from natural mass slope erosion processes. (Natural surface erosion and delivery is expected to be insignificant from undisturbed forested watersheds.)

The starting point for the natural sediment yield component of the model (Figure 2) is the value 25 tons of sediment per square mile per year (Table 1). This value is for landscapes developed under the influence of water erosion on granitic slopes with gradients near 60 percent. Values are in terms of sediment delivered to streams and were measured in streams using sediment traps estimated to be 80 percent efficient. The range of 10 to 100 tons/square mile/year is an estimate of reasonable variance from the normal value on steeper and less steep landscapes. The range is thought to be generally valid for forested landscapes in the interior west. (Megahan, personal communication.)

Table 1--Sediment yield estimates for granitic landscapes

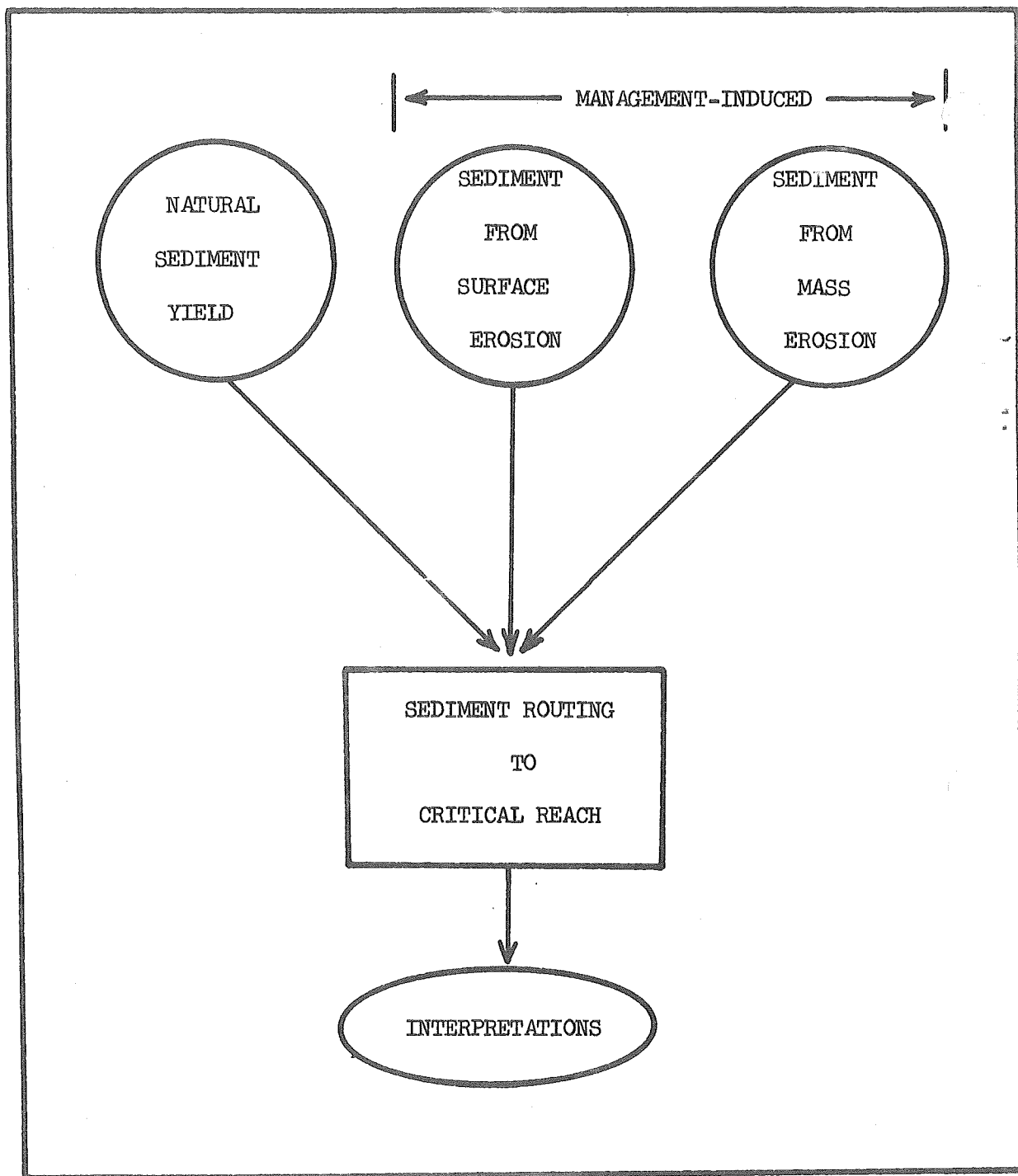| Type of Landscape	Average Sediment Rate Tons per Square Mile Per Year
High sediment producing areas (4 x "normal")	100
"Normal" sediment producing areas	25
Low sediment producing areas (0.4 x "normal")	10

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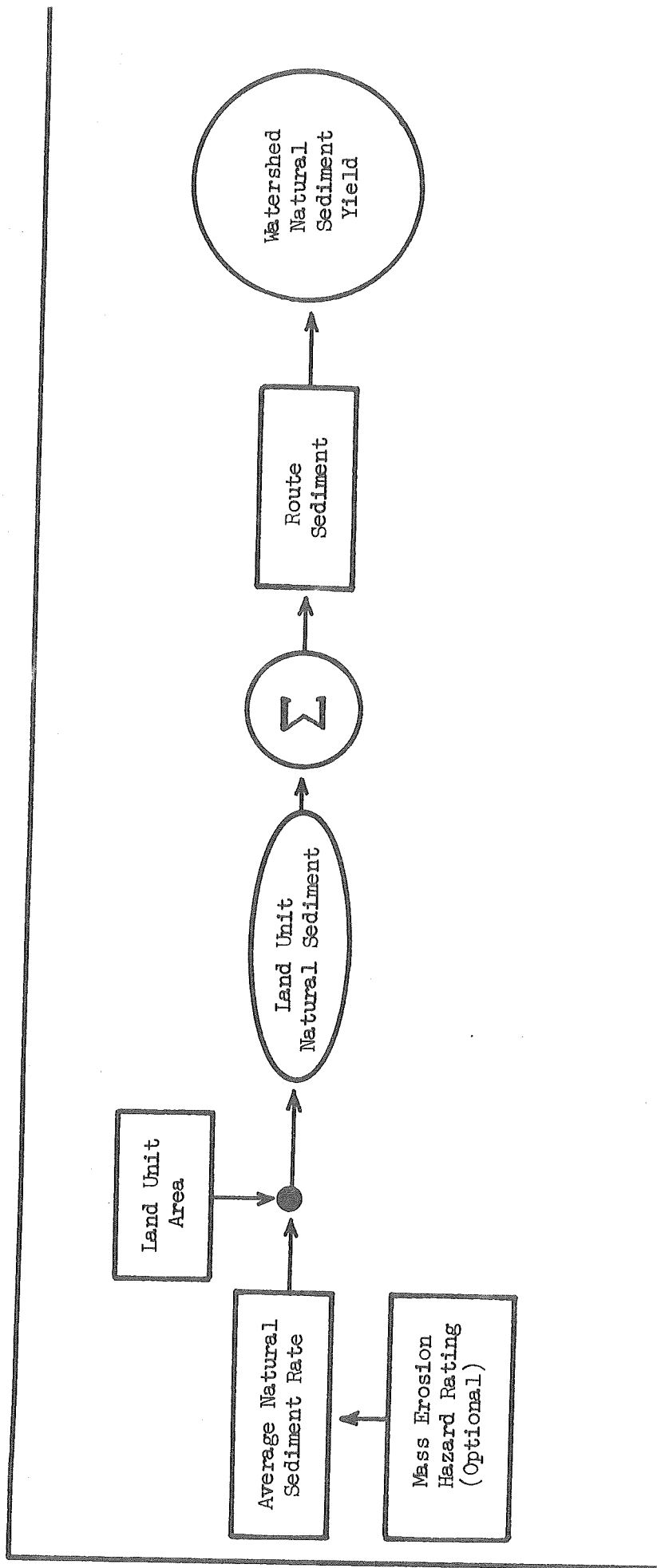Figure 1: Generalized diagram of sediment yield model components.

Figure 2: Process flow chart - Natural Sediment Yield.

Watersheds from which this data was measured ranged in size from 0.1 to 2.5 square miles with an average drainage area near 1.0 square mile. Landtypes found within these watersheds are predominantly strongly dissected mountain slope land, as described by the Boise National Forest Land Systems Inventory (Wendt 1973). See Appendix B for descriptions of these landtypes. Extrapolations should use these descriptions as a reference for applying the 25 tons per square mile per year value to local map units. Since natural surface erosion is considered insignificant, the variation in natural sediment yield is assumed attributable to differences in mass erosion hazards and delivery differences.

Forest personnel are encouraged to identify the landtype on their Forest with similar characteristics for extrapolation to identify the landtype which would be equivalent to the average natural sediment rate of 25 tons/square mile/year. Those who feel confident in extrapolating base sediment for other landtypes on their Forest, based on data or other defensible techniques, are encouraged to use their local expertise to do so. Where this is done, the process or procedure used should be fully documented. A procedure is proposed for extrapolation to other landtypes where better estimates are not available. In lieu of the proposed procedure for estimating the average natural sediment rate for individual land units, some Forests may feel more comfortable using USLE or other approaches for this purpose if surface erosion is significant for the area under consideration. It should be noted that most USLE factors will have to be adjusted for the geographic area under consideration. On-site erosion estimates generated by methods other than those developed in this guide (e.g., USLE) will have to have sediment delivery ratios applied to them to express erosion as sediment for later comparison.

In order to express the variability of natural sediment yields, a functional relationship relating mass erosion hazards to average natural sediment rates is proposed. Since natural surface erosion is assumed insignificant, land units with high mass erosion hazards are assumed to have high sediment yields. Hazard ratings are qualitative, relative interpretations of land units within a watershed. Guidance for the development of mass erosion hazard ratings and explanations of site characteristics to consider can be found in WRENSS[1]--Chapter 5, Soil Mass Movement.
Most Forests already have mass hazard erosion ratings available as part of the land systems inventory. To use the procedure described here, mass erosion hazard ratings will have to be developed for each land unit using the rating procedure given in Chapter 5 of WRENSS.

For the purposes of developing hazard ratings, soil mass movement is classified into two major types: debris avalanches-debris flows and slump-earthflows. A hazard rating of the natural hazard of each type of mass movement is provided in WRENSS (Tables V.5 and V.7). The relative importance of each type of soil mass movement must be evaluated for the area of model application and the appropriate mass erosion hazard rating used.

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1 U.S. Forest Service. 1980. An approach to water resource evaluation non-point sources-silviculture (WRENSS), a procedural handbook. U.S. Environmental Protection Agency, Athens, Georgia, EPA-600/8-80-012, August 1980 (available from National Tech. Information Service, Springfield, VA 22161).

A relationship betweeen mass erosion hazard ratings (valid for either debris avalanches-debris flows or slump-earthflows) and the average natural sediment rate has been developed (Figure 3). The reference landtype to which the value 25 tons per square mile per year applies has a hazard rating of 33 using the rating procedure for determining natural hazard of debris avalanche-debris flow failures in WRENSS. Minimum and maximum possible hazard rating end points were equated to the range of average annual sediment rates (10 to 100 tons/square mile/year, respectively) and a curvilinear line graphically fitted between these points. Once hazard ratings are developed for each land unit, one simply enters the graph in Figure 3 to obtain an estimate of the average natural sediment rate for that land unit. Application of this procedure to all land units will provide an array of values defining the range of average natural sediment rates.

The following steps outline the overall procedure for estimating average natural sediment yield (see Figure 2):

Step 1.   Delineate the watershed of interest above the critical reach.

Step 2.   Overlay the watershed with land units (landtypes).

Step 3.   Determine the average natural sediment rate by one of the following methods.

   (a)   Extrapolate using local data and local expertise, or

   (b)   Determine mass erosion hazard ratings as given in WRENSS-Chapter 5 and obtain average natural sediment rate using the graph in Figure 3.

   (c)   Use USLE or other technique for estimating on-site erosion and apply a slope sediment delivery ratio.

Step 4.   Multiply the average natural sediment rate by the land unit area to obtain the land unit natural sediment.

Step 5.   Repeat Step 3 and 4 for each land unit, sum the sediment from all land units and convert to $T/mi^2/yr$ to obtain a weighted average for the watershed.

Step 6.   Route sediment to critical reach. (Procedure to be discussed in subsequent section.)

   2.   Sediment From Surface Erosion

Surface erosion in a natural (undisturbed) forested watershed is insignificant. Surface erosion, however, becomes an important sediment producing process on lands disturbed by man's activities. In addition, transport of surface eroded material from slopes to channels is a fluvial process rather than a gravitational process. For these two reasons, sediment derived from management-induced surface erosion and sediment derived from management induced mass erosion are treated as separate and independant processes.
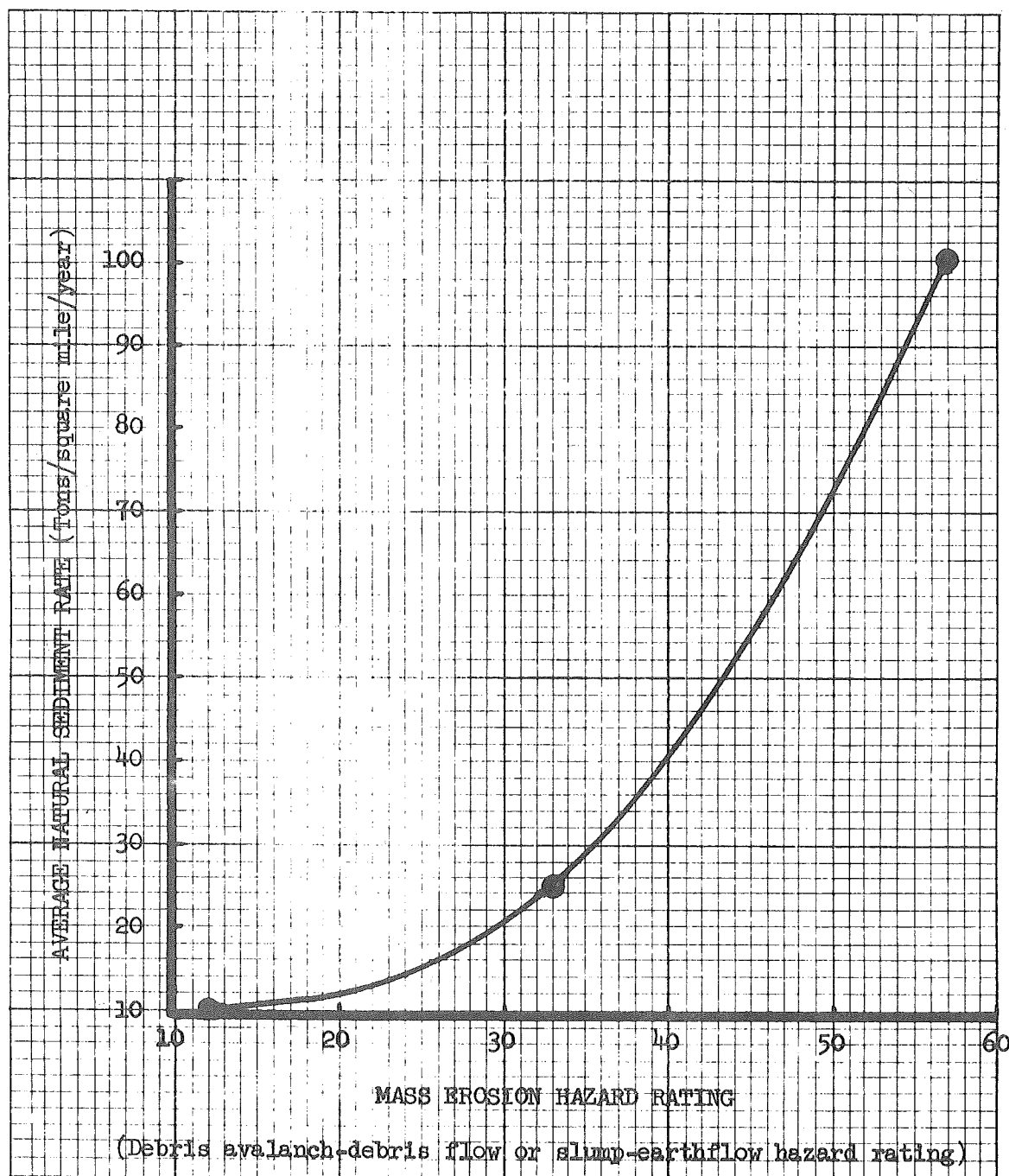
Figure 3: Average natural sediment rate as a function of natural mass erosion hazard rating.

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Significant sources of sediment due to management activities considered by this model are roads, fire, and logging (Figure 4). Erosion rates for other man-caused sediment producing activities must be developed by the user. Data for this effort comes primarily from research conducted by W. F. Megahan (Megahan 1974 and 1975; Megahan and Kidd 1972; Megahan and Molitor 1975; Rice, Rothacher, and Megahan 1972; Platts and Megahan 1975) supplemented by data from Anderson (1975a and b) and Andre and Anderson (1961). The values developed represent the amount of additional sediment produced due to surface erosion resulting from management activities.

The model for management-induced surface erosion is based on research data that suggests a basic soil loss rate associated with roads, fire, and logging, which are reduced as a function of time since the activity took place. The erosion rates in the model are modified by the dominant controlling variables on the land unit on which they occur, the magnitude of the activity, specific characteristics of the activity, and possible mitigation factors. Slope sediment delivery is estimated as a function of land unit characteristics to route eroded material from its source to the stream system.

A comparison of erosion for materials derived from a variety of rock types is provided by Andre and Anderson (1961) and appears in Table 2.

Table 2 - Mean surface aggregation ratio and derived geologic erosion factors for soils from different rock types in California.

Rock Type	Mean Surface Aggregation Ratio	Coefficient of Variation (Percent)	Geologic Erosion Factor
Acid igneous (granitic)	118	35	1.0
Basic igneous	49	53	.42
Serpentine	41	44	.35
Miscellaneous metamorphic	46	50	.39
Schist	89	67	.75
Hard sediments	61	18	.52
Soft sediments	78	83	.66
Alluvium	124	88	1.05

These authors related erosion to the mean surface aggregation ratio of surface soils. Another article by Anderson (1975b) portrays surface aggregation ratios for granitic rock ranging from 149 to 71, hence the value 118 from the 1961 article seems reasonable as a basis for comparison. Coefficients of variation are included to provide a perspective on data reliability. This is particularly important in variable materials like alluvium where one standard deviation is 88 percent of the mean value of the original data. The geologic erosion factor is obtained by dividing the mean surface aggregation ratio of soils from each rock type by 118.
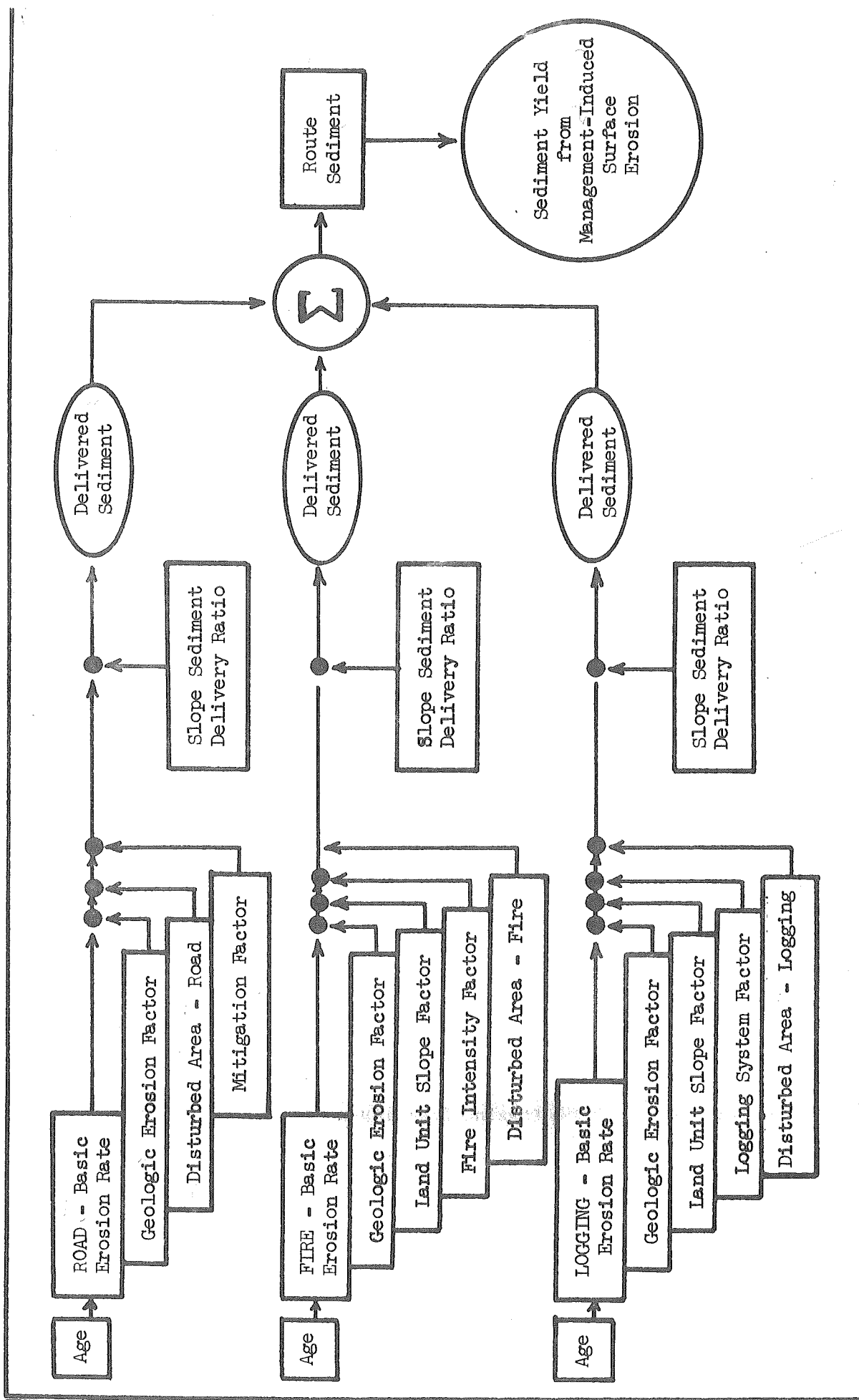
Figure 4: Process Flow Chart – Sediment Yield from Management–Induced Surface Erosion.

Geologic erosion factors in Table 2 are used as coefficients to modify basic erosion rates for areas underlain by bedrock other than granitics. As an example, a geologic erosion factor of 0.39 would be applied to Belt Supergroup rocks of northern Idaho which are classified as miscellaneous hard met..morphic rocks. Similar extrapolations are made for all activities occurring on bedrocks other than granitics to adjust basic erosion rates to specific sites by multiplying by the appropriate geologic erosion factor. It should be noted that the values in Table 2 are not all inclusive of the possible bedrock types that may be encountered.

a. Management Effects

(1) Roads

Roads in the Idaho Batholith are assumed to have basic erosion rates (Table 3) based on sediment data from a "standard" maintained 16-foot native material road with ditch (Megahan 1974 and personal communication). Basic road erosion rates are modified by the geologic erosion factor and multiplied by the disturbed area of the road prism segment. The road prism used in this context is the total area disturbed including subgrade, cut and fill slopes, ditches, berms, turnouts, and any other constructed features when present. Tables of geometry for low standard roads (Megahan 1976) are helpful to determine total area disturbed. The total area disturbed factor generally adequately handles deviations from the 16-foot standard road which involves changes in road width. It also handles deviations resulting from roads located on various side slopes.

Table 3 - Basic erosion rates for standard practices in tons per square mile per year.

| Practice | Year | | | | | | |
	1	2	3	4	5	6	7+
Roads 1/	67,500	18,000	5,000	5,000	5,000	5,000	5,000
Fire 2/	550	120	25	5	0	0	0
Logging 3/	340	180	140	90	40	20	0

$\varepsilon = 700$

$\varepsilon = 810$

1/ Road area includes horizontal distance from toe of fill to top of cut. Standard 16-foot road assumed to have sustained 5-7 percent grade, balanced construction, insloped with ditch, native surface, and cross drains at 500-foot spacing constructed in granitic materials on a 50 percent side slope and is annually maintained.

2/ Standard fire is assumed to have burned at high intensity and consumed at least 40 percent of standing vegetation. Side slope is assumed to be approximately 45 percent.

3/ Standard logging system is clearcut with tractor yarding. Temporary roads and skid trails are assumed cross ditched and seeded as part of standard logging practice.

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Roads to be considered include all system roads in the watershed and any major constructed temporary road system. Nonspecified roads and skid trails internal to logging units are considered as part of logging effects discussed in the next section and should not be duplicated here.

Basic erosion rates for roads were derived from Megahan's data (unpublished) and distributed over time in accordance with the shape of logarithmic functions (Anderson, 1975b). Megahan's data indicates initial road sediment yield from small watersheds in the Idaho Batholith averaged 54,000 tons per square mile per year. Sediment delivery on these small watersheds was assumed near 100 percent, and sediment traps were estimated to be 80 percent efficient. Dividing 54,000 by trap efficiency (0.8) yields the starting value of 67,500 in table 3. The estimated time to return to a stable value of 5,000 tons per square mile per year in 3 years forms the other end point.

Mitigation measures are applied to basic road erosion rates in the form of a percentage reduction depending upon the intensity of measures applied. Reductions in erosion due to mitigation measures are presented in Table 4.

Reduction in erosion in Table 4 for vegetative mitigation measures are derived from research in the Idaho Batholith (Megahan and Kidd, 1972) with additional factors for physical mitigation measures estimated to serve as approximations of expected erosion reduction. These values are intended as guidelines for areas where local data is not available. They are highly variable and judgment and common sense should be used in their application. Mitigation is assumed to be applied promptly before the first year's sediment is produced.

Table 4 - Suggested erosion reduction percentages for various mitigation measures.

Mitigation Measures	Percent Reduction in Erosion (Percent)
Vegetative measures	
Seed and fertilizer application	25
Plant ponderosa pine, seed, and fertilize	28
Wood chip mulch, seed, and fertilize	37
Straw mulch, seed, and fertilize	43
Netting in aspen blanket, seed, and fertilize	56
Asphalt and mulch	57
Mulch and net, seed, and fertilize	58
Sod	60
Physical measures	
Road tread surfaced	20-25
Road grade 5% or less	2
Rip-rap fill	50
Road partially closed (no maintenance)	75
Road permanently closed (obliterated)	95
Buffer strips along water course[1]	10-15
Filter windrows (slash or baled straw) at bottom of fill slope	35-40

[1] As specified in Packer, P. E. and G. F. Christensen (1964).

If this assumption cannot be reasonably made, mitigation factors should be adjusted accordingly. Road closure mitigation measures are applied beginning with the erosional season after roads are closed.

Mitigation can generally be summed with the limitation that mitigation measures can only reduce a maximum of 80 percent of the erosion with the exception of roads that are to be obliterated where 95% of the erosion can be eliminated by obliteration. The mitigation factor to be applied to the model is obtained by subtracting the sum of all mitigation measures to be applied from 1. The resulting mitigation factor (a value ranging from 1.0 to 0.2) is then applied to the basic road erosion rates to reduce the amount of soil loss expected to occur.

Basic road erosion rates are modified as needed to apply to other than the standard road. Road erosion rates are then multiplied by the geologic erosion factor, the mitigation factor and the area disturbed by the road to arrive at total on-site erosion due to roads. This calculation is applied to road segments within each land unit. The analysis is repeated for any time period of interest to planning using reduced basic road erosion rates as shown in Table 3 for subsequent years.

(2) Fire

Fire has been shown to increase sediment yield from a variety of landscapes (Tiedemann et al. 1979). The amount of increase is extremely variable and can be attributed to intensity of burn, slope gradient, and proximity to streams. Megahan and Molitor (1975) report that a very intense fire produced approximately 550 tons/square mile the first year after the burn . Megahan (personal communication) indicates that this increase should return to near natural levels after approximately four years. This information was used to derive basic erosion rates for fire (Table 3) using a logarithmic function to scale recovery rates to pre-fire conditions. The standard reference fire is assumed to have burned at very high intensity. Fires of less burn intensity do not destroy as much of the vegetation, litter, and humus that protect the soil surface from erosion. Therefore, the basic erosion rate from fire is modified by a fire intensity factor which decreases basic erosion rates.

Fire intensity classes of low, medium, and high are determined as described in the Burn-Area Emergency Rehabilitation Handbook (FSH 2509.13 - Chapter 20 - Section 23.31) and presented in Table 5.

The standard fire is one of high intensity and therefore is assigned a fire intensity factor of 1.0. Connaughton (1935) studied erosion relative to fire intensity as a percentage of study plots showing erosion after fire. Approximately half as many plots showed erosion under medium intensity fire compared to high intensity fire and low intensity fire caused erosion in 20 percent of the plots. Based on his findings, fire intensity factors of 0.5 on 0.2 are assigned to medium and low intensity fires, respectively, in Table 5. These factors are used to modify the basic fire erosion rates in Table 4 according to the intensity of burn. An average fire intensity factor is determined for each land unit by weighted averaging fire intensity factors according to the percent of the area burned in each fire intensity class.

Basic fire erosion rates and intensity factors refer to both wildfire and controlled burning. The variability in sediment production from both types of

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fires is great and a function of factorspreviously mentioned. A conservative average value has been selected. It should be adjusted to local conditions depending on the level of planning involved. The introduction of probability of occurrence concepts may be appropriate when analyzing wildfires in a planning context.

Table 5 - Fire intensity classes and corresponding fire intensity factors

Fire Intensity Class	Description	Fire Intensity Factor
Low	Soil surface litter and humus have not been destroyed by fire. (a) Root crowns and surface roots will resprout. (b) Potential surface erosion has not changed as a result of fire.	0.2
Medium	On up to 40 percent of the area, the soil surface litter and humus have been destroyed by fire and the A horizon has had intensive heating. (a) Crusting of soil surface produces accelerated surface erosion. (b) Intensively burned areas may be water repellent. (c) Root crowns and surface roots of grasses in the intensively burned area are dead and will not resprout.	0.5
High	On 40 percent or more of the area, soil surface litter and humus have been completely destroyed by fire and the A horizon has had intensive heating. (a) Crusting of soil surface produces accelerated surface erosion. (b) Intensively burned areas may be water repellent. (c) Root crowns and surface roots of grasses in the intensively burned areas are dead and will not resprout.	1.0

Three possible combinations of logging plus fire can occur: (1) slash burning in conjunction with a logging operation; (2) wildfire on a previously logged area; and (3) wildfire followed by salvage logging. Additive models of fire and logging effects are suggested to estimate surface erosion on the areas affected.

Surface erosion in areas disturbed by fire (and logging) is also assumed to vary by topographical characteristics of landforms - primarily slope; that is, steeper slopes will increase erosion rates more than gentler slopes. It was assumed that this variability is generally in the range 0.5 to 2.0 of the basic erosion rates for slopes in the range of 10-75 percent. The relative value of this modifier is adapted from the slope factor relationship of the Universal Soil Loss Equation scaled from 0.5 to 2.0 using equation 1. This

means that when the land unit slope factor is applied to basic fire and logging erosion rates, activities on slopes of zero percent will have basic erosion rates reduced by one-half (a factor of 0.5), slopes of 45 percent are the base with a factor of 1.0, and slopes of 75 percent, with a factor of 2.0, will cause the basic erosion rate to double.

$$\text{Land unit slope factor} = \frac{((0.43 + 0.30s + 0.043s^2) \times 0.0374)}{6.613} + 0.50 \quad (1)$$

where: s = average slope of land unit in percent.

The land unit slope factor is applied to the basic fire erosion rates as are the fire intensity and geologic erosion factor to modify the erosion rates to reflect site-specific conditions. The modified erosion rate is then multiplied by the area disturbed by fire to arrive at total on-site erosion due to fire. The calculation is applied to the fire for each land unit within which the fire occurred. The analysis is repeated for any number of years of interest to planning.

(3) Logging

Basic erosion rates for clearcut logging with tractor yarding over time are shown in Table 3. Again, a logarithmic recovery function is used but the literature does not supply the end points on the curve in a convenient form. Anderson (1975b) indicates a measured total increase in sediment of 2 to 3 times the amount of sediment previous to logging for a variety of logging systems in Oregon. Megahan and Kidd (1972) found an average increase of 60 percent in sediment yield for a six-year period following skyline logging in Idaho. Based on this data, the logarithmic distribution function used to distribute sediment over the assumed 6-year recovery period indicated that 2.5 times the sediment normally produced should appear the first year decreasing to 0 for any time longer than 6 years. Since the data was measured as instream sediment values, it must be transformed to on-site erosion using a delivery ratio. The calculation for the first year's erosion appears in equation 2.

$$\frac{((2.5 \times 75) - 75)}{0.33} = 341 \text{ T/mi}^2/\text{yr} \quad (2)$$

Where: 2.5 is the factor of increased erosion over natural, 75 is the tons of sediment produced by natural erosion assuming a delivery ratio of 0.33 (Boyce, 1975) on watersheds averaging 1 square mile in size, and 0.33 is the factor of conversion from skyline to tractor logging (table 6). The value of 75 is subtracted to get rid of natural erosion since the two processes are considered independently (75 tons erosion on-site is equivalent to 25 tons of sediment delivered to streams if the delivery ratio is 0.33).

Megahan (1980) published a table portraying the percentage of land surface disturbed by a variety of logging systems and cutting prescriptions. This information is adapted to this model and appears in table 6.

Table 6 - Derived logging system erosion factors for various logging systems and cutting prescriptions (after Megahan, 1980).

Logging system 1/	Bare soil (%)	Logging system erosion factor
	Clearcut logging	
Tractor	21	1.00
Cable	13	.62
Skyline	7	.33
Aerial	4	.19
	Selection logging	
Tractor	15	.71
Cable	9	.43
Skyline	6	.29
Aerial	3	.14

1/ See Glossary (Appendix A) for definitions of logging systems.

Logging system erosion factors were calculated from the averages of similar logging systems and cutting prescriptions using the tractor clearcut as a base reference value. This adjustment assumes that erosion is proportional to the percent bare soil observed for various logging systems. The logging system factors are used to modify basic logging rates according to logging system used to harvest timber.

Basic logging erosion rates are modified using the logging system erosion factor, the geologic erosion factor, the land unit slope factor, and the area actually disturbed by logging to arrive at total on-site erosion due to logging. This calculation is applied to cutting units within each land unit. The analysis can be repeated for any time period needed for planning.

b.   Slope Delivery

As each surface erosion source is estimated, the eroded material must be delivered downslope to the stream system. This process when applied to each management activity stratified by land units within the watershed system, provides a gross estimate of potential sediment derived from surface erosion available to the stream system. The fluvial delivery process is a function of many variables. Wischmeier and Smith (1978) and Boyce (1975) provide general discussions of the process. WRENSS provides a systematic technique for determining slope delivery efficiency in Chapter 4, Surface Erosion, on pages IV-54 to IV-57.

It involves calculating the relative area derived from a polygon as a function of eight land characteristics, and applying this area to a conversion curve to determine slope sediment delivery. A slope sediment delivery coefficient must be developed for each land unit (landtype) being considered.

It is recommended that an adapted form of the WRENSS sediment delivery technique be used. Some of the eight variables in WRENSS may not be

applicable or significant in certain circumstances. Consequently, Forests will have to adapt the techniques to local conditions and data availability. In most applications, users will want to eliminate some of the eight factors either because they are not relevant to their area or because data is not available.

The following steps outline the overall procedure for estimating sediment from surface erosion (see Figure 4):

Step 1   Determine activities to be carried out within the watershed of interest. Same as watershed used to calculate natural sediment yield.

Step 2   Assemble information for each type of activity by land units
          Roads: (1) Basic erosion rate for time period (age) to be modeled.
                      (2) Area disturbed by roads
                      (3) Mitigation measures to be used

          Fire: (1) Basic erosion rate for time period (age) to be modeled.
                      (2) Area disturbed by fire
                      (3) Average fire intensity class for area burned
                      (4) Average land unit slope

          Logging: (1) Basic erosion rate for time period (age) to be modeled.
                      (2) Logging system utilized
                      (3) Area disturbed by logging
                      (4) Average land unit slope

Step 3   By land types within each activity multiply the basic erosion rates for that activity by the geologic erosion factor and the factors from Step 2 applicable to that activity.

Step 4   Multiply by the slope sediment delivery coefficient to obtain sediment delivered to stream.

Step 5   Sum the delivered sediment from all land units and repeat Steps 3 and 4 for each activity.

Step 6   Sum the sediment delivered from all activities and convert to tons/square mile/year to obtain a weighted average for the watershed.

Step 7   Route sediment to critical reach (procedure to be discussed in subsequent section).

Step 8   Repeat Steps 2 through 7 for additional years for which sediment yields are needed.

3.   Sediment From Mass Erosion

Mass erosion processes are distinctly different from surface erosion processes. Even though they may respond to similar driving variables, the two

processes respond differently to those variables. For this reason, sediment resulting from management-induced mass erosion is considered as a separate component in this model. Estimation of mass erosion is the most difficult, least understood, and hardest to quantify of the various components of this model.

Sediment from management-induced mass erosion may in many cases be an insignificant component in the estimation of total sediment. In these cases, it might reasonably be ignored in planning. Even if the potential exists, management-induced mass erosion hazards can be handled in planning by providing management direction so that certain activities will not be allowed to take place on land units with high mass erosion hazards.

If sediment from mass erosion due to management is significant, some estimate of sediment quantities is necessary. Chapter 5 in WRENSS prepared by D. Swanston and F. Swanson contains a state-of-the-art review of soil mass movement and provides a basis for evaluating soil mass movement. The chapter identifies the primary elements necessary to evaluate the processes, and presents a methodology for obtaining quantitative estimates of sediment yield using data which must be developed locally.

In summary, if sediment from management-induced mass erosion is potentially a significant element in the watershed-sediment system, it should be estimated and quantified. The procedural techniques used should be based on the WRENSS procedure and must be developed by individual Forests.

4. Sediment Routing

Sediment delivered to channels must be transported through the stream system to the critical reach. Some of the sediment will be temporarily stored in channels and the rest will be tranported downstream. Local scour will pick up additional sediment that may be deposited at some point farther downstream or transported out of the watershed. The complexity of hydraulic variables in sediment routing is immense. Eight variables are considered most important including: stream discharge, width, depth, gradient, velocity, roughness of bed and bank materials, concentration of sediment, and size of sediment debris. Close interdependence between many of the variables often precludes the establishment of one-value relationships. In general, there is considerable variation in the results obtained from sediment transport equations. In addition, organic debris in lower order channels further complicates the sediment transport process.

Several formulas have been developed which attempt to describe this process and predict sediment yield at some point downstream. Since physical stream characteristics vary greatly among streams and along a single stream channel, use of these predictive equations requires detailed analyses of scores of channel segments. Sediment would need to be routed through each of these segments to arrive at sediment delivery to the critical reach. This requires short-term increments of predicted sediment inputs and streamflow rate which is only a practical methodology for detailed studies. Sediment yield formulas, at best, can only be expected to provide an estimate for a specific set of conditions (ASCE, 1975; Shen, 1971). In most forested mountain

watersheds, the energy available for sediment transport exceeds sediment
supplies invalidating the use of most sediment transport equations. The
limitations associated with existing sediment yield formulas invalidates their
effectiveness in routing sediment through stream channels for Forest planning.
Therefore, a more generalized procedure is used.

A basic premise is that the sediment yield rate for a large watershed is less
than the sum of the sediment yield rates computed from its subwatersheds. If
this is not done, sediment yield rates would not decrease with increasing
watershed area as numerous studies have indicated (Boyce, 1975). This
reduction is accomplished through the application of a channel sediment
routing coefficient. The sediment that is not delivered to the critical reach
is accounted for as channel storage consisting of storage in tributary
channels, alluvial fans, floodplains, and behind organic debris.

The procedure selected is a modification of an empirical relation derived by
Roehl (1962) using data from several locations in the United States. Roehl's
sediment delivery ratios were derived from comparisons of erosion from small
field plots and sediment trapped in downstream reservoirs. All losses due to
surface and channel storage are incorporated into this relation. The model
developed here delivers sediment from slopes to active first order drainages.
The quantities determined reflect losses from surface storage but not for
channel storage in a stream system. In order to avoid double accounting of
hill slope storage, Roehl's graph has been shifted so that the channel
sediment routing coefficient (Roehl's sediment delivery ratio) for watersheds
up to one square mile is equal to 1.0 (Figure 5). An upward shift of the
curve is further justified on the grounds that forested watershed generally
have steeper slopes than the average watersheds studied by Roehl and,
therefore, should be expected to deliver greater amounts of sediment to the
stream system.

To arrive at the amount of sediment delivered to the critical reach, the
natural and management-induced sediment yields are modified by the appropriate
channel sediment routing coefficient based on the area of the planning
watershed.

The following steps outline the overall procedure for routing sediment to
critical reaches (see Figures 2, 4, and 5).

Step 1   Obtain the drainage area of the watershed above the critical reach.

Step 2   Obtain the corresponding channel sediment routing coefficient for the
          drainage area using the graph in Figure 5.

Step 3   Multiply the sediment yields for natural sediment, sediment from
          surface erosion, and sediment from mass erosion by the channel
          sediment routing coefficient to arrive at the corresponding sediment
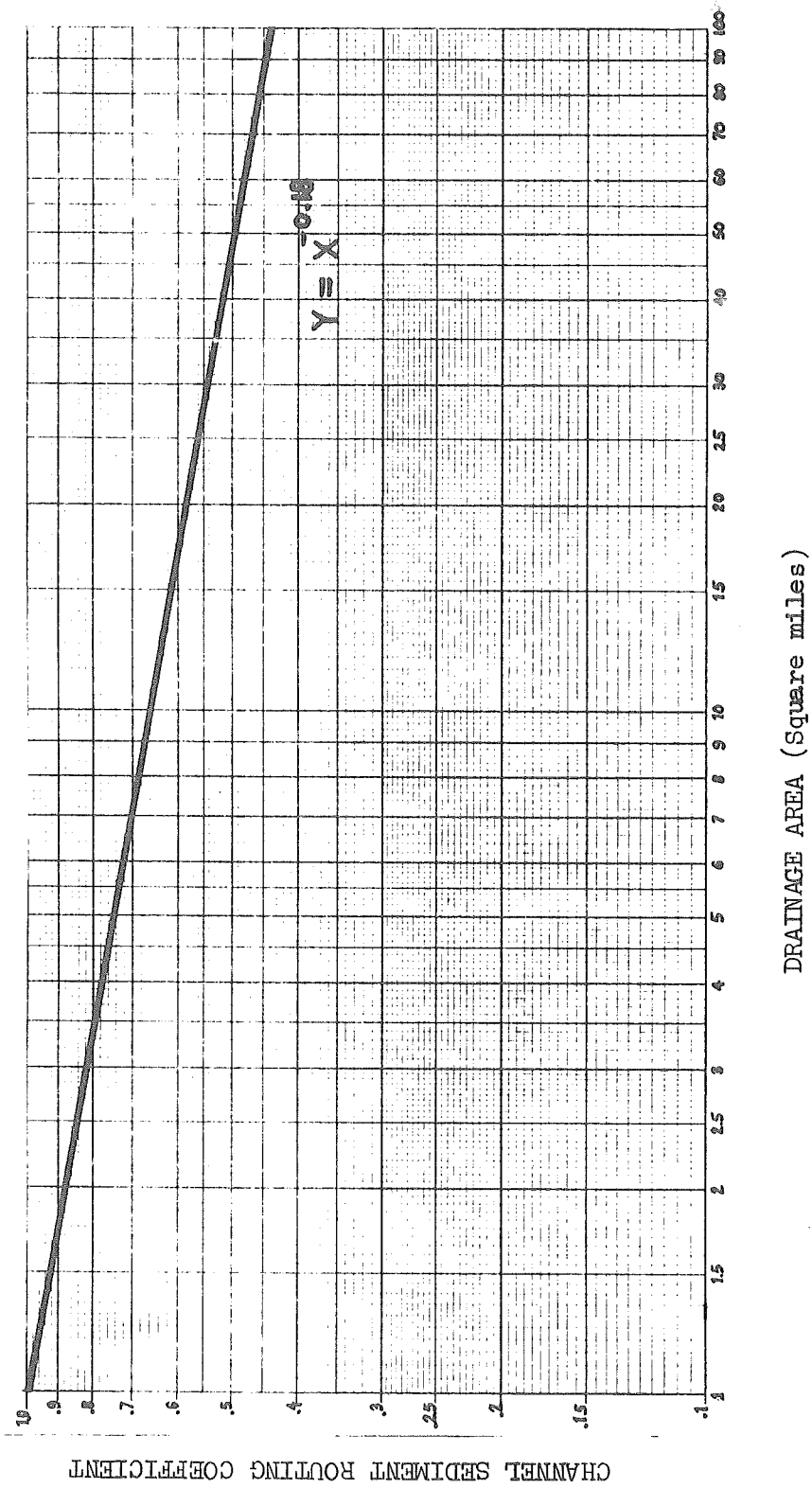   yields at the critical reach for each type of sediment yield.

DRAINAGE AREA (Square miles)

Figure 5: Channel sediment routing coefficient as it relates to drainage area in forested watersheds.

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INTERPRETATIONS AND APPLICATION

The watershed-sediment phenomenon represents an extremely complex and highly variable system. Its basic elements: disturbance, erosion, slope hydrology, sediment transport, and sediment disposition (scour and deposition) are individually complex and are often poorly defined. The elements are interactive. Any procedural technique or model, by necessity, must simplify and key on what are expected to be the primary and dominant controlling variables to produce a workable tool. The obvious dangers of this are oversimplification and nonrepresentation of the real-world system.

The conceptual model outlined in this guide is a very basic model. Individual processes are generally representative of observed responses in the Idaho Batholith. Features have been added to reflect the variability of these responses over the different land units that occur in the Idaho Batholith, and to extrapolate general responses to areas near the general boundaries of the Batholith.

A precise model is not intended. It is recommended that Forests follow the conceptual process, modifying specific values where local data or techniques are more applicable.

The value of the model's output is most valid when it is used to compare responses of different alternatives. Confidence is expected to decrease when absolute quantitative results are specifically used, and as the process is applied geographically further from the data source--the Idaho Batholith.

Two significant physical processes need more development. They are channel routing and sediment disposition. Channel routing to the critical reach is handled in the model by a general response curve based on data derived around the United States. For planning applications, this method is appropriate but should be localized and tested by research. The channel routing component of this model is definitely the weakest link in attempting to model the erosion and sediment transport process. Sediment routing was only included so that fisheries interpretations about the impact of sediment at critical reaches could be made. If these interpretations are not needed, users may wish to avoid attempting to route sediment through the watershed. No attempt is made to determine how sediment will be distributed within a critical reach, which includes deposition, scour, and sediment passing completely through the reach. Disposition of sediment in the critical reach should receive a high research priority as it has a profound effect on fisheries interpretations, channel condition, and water quality effects. At the present state of the art, the data needed for detailed sediment routing cannot be practically obtained in the realm of current National Forest System data acquisition efforts.

The conceptual model estimates quantitative average annual sediment yields at the critical reach derived from:

A. Natural sediment yield;

B. Sediment from management-induced surface erosion; and

C. Sediment from management-induced mass erosion.

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These three sediment sources are summed to produce total sediment yield for the watershed under a given management scenario at a given time and then compared with natural sediment yields. Total sediment yield is calculated using equation 3.

$$\text{Total sediment yield} = A + B + C \qquad (3)$$

where: A = natural sediment yield; B = sediment from management-induced surface erosion; and C = sediment from management-induced mass erosion. All values are in terms of tons/square mile/year.

Natural sediment yield is assumed to remain virtually unchanged over time on an average basis and, therefore, is the basis for comparison. Sediment due to management activities is the dynamic component in evaluating management effects. For planning purposes, interest will generally center around defining natural undisturbed sediment yield, the sediment yield under current management conditions, and the expected sediment yield for an array of proposed management strategies. In most instances, estimates of management-induced sediment yields will be desired for time periods ranging from 5 to 10 years into the future. The model developed here has the capability to provide these outputs.

Model outputs can be expressed as a definite quantity of sediment delivered to some point in a watershed, or as a relative index of sediment increase resulting from management activities at some point in a watershed. The type of output generated is a function of the purpose for which the sediment yield prediction is made. In general, greater reliability can be placed on relative evaluations of sediment yield increases than on absolute estimates of sediment quantity. All output values in the model are expressed as "average annual" quantities. These events are rarely observed in nature, but they are the most reliable events to statistically evaluate and verify. Average annual sediment yields should be thought of in the same context as the average annual erosion predictions derived using the Universal Soil Loss Equation. Predictions will differ considerably from actual sediment yield for any single year due to deviations in climatic conditions in any single year from the average. However, as a relative comparative tool, predicted yields still have value. Validation of predicted values must be based on the average of a number of years of data for a valid comparison.

It may be argued that extreme events (low frequency, high intensity) should be evaluated, since they are the most spectacular and do produce large quantities of sediment. However, a general technique is not available to do this with any reliability. On the other hand, average annual quantities and changes can be correlated to extreme events if such interpretations are required. It should be noted, that the extreme event argument is often countered by the notion that higher frequency events, that is, average flows, although less spectacular, are more responsive to management while rare events are not influenced significantly by management. This point of view argues that watersheds will react almost identically during low frequency, high intensity events regardless of the degree of management activities superimposed by man. That is to say, tremendous quantities of sediment will be mobilized during these events as part of the natural functioning of the watershed system.

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Consequently, management effects are best observed and evaluated in relation to more common (average) flows. If this is true, then "average" event resolution is further supported.

When outputs are expressed as increases in sediment yield, the following standardized equations are recommended:

$$\text{Sediment yield increase (\%)} \atop \text{(as a percent of natural)} = \frac{\text{Total sediment yield}}{\text{Natural sediment yield}} \times 100$$

$$= \frac{(A + B + C)}{A} \times 100 \qquad (4)$$

$$\text{Sediment yield increase (\%)} \atop \text{(as a percent over natural)} = \frac{\text{Sediment increase due to management}}{\text{Natural sediment yield}} \times 100$$

$$= \frac{(B + C)}{A} \times 100 \qquad (5a)$$

$$= \left[\frac{(A + B + C)}{A} \times 100 \right] - 100 \qquad (5b)$$

Where: A, B, and C are as previously defined.

Using equation 4, a doubling of total sediment in the stream is expressed as an increase of 200 percent of natural, or is more commonly referred to as 2 times natural. Using equation 5, a doubling of sediment in the stream is expressed as a 100 percent increase over natural. User's are cautioned to be very careful in selecting terminology when referring to sediment yield increases because an increase of 200 percent of natural is not the same as an increase of 200 percent over natural. Fishery interpretations currently use equation 5b and it is recommended that this form be adopted for general use.

The major reason for calculating sediment yield increase according to equations 4 or 5b is that the quantity (A+B+C), that is, total sediment yield, is a measurable quantity for monitoring purposes. The quantity (B+C), on the other hand, in equation 5a, which is the quantity of sediment produced due to management alone, should not be used because this amount of sediment cannot be meaningfully separated from total sediment for monitoring purposes. Increasingly we are required to monitor how well our predictions conform to real-life situations. The National Forest Management Act specifically states that the Forest Service must be able to monitor the Forest Plan. The results of monitoring can only be used to evaluate the attainment of planning objectives when used in either equations 4 or 5b.
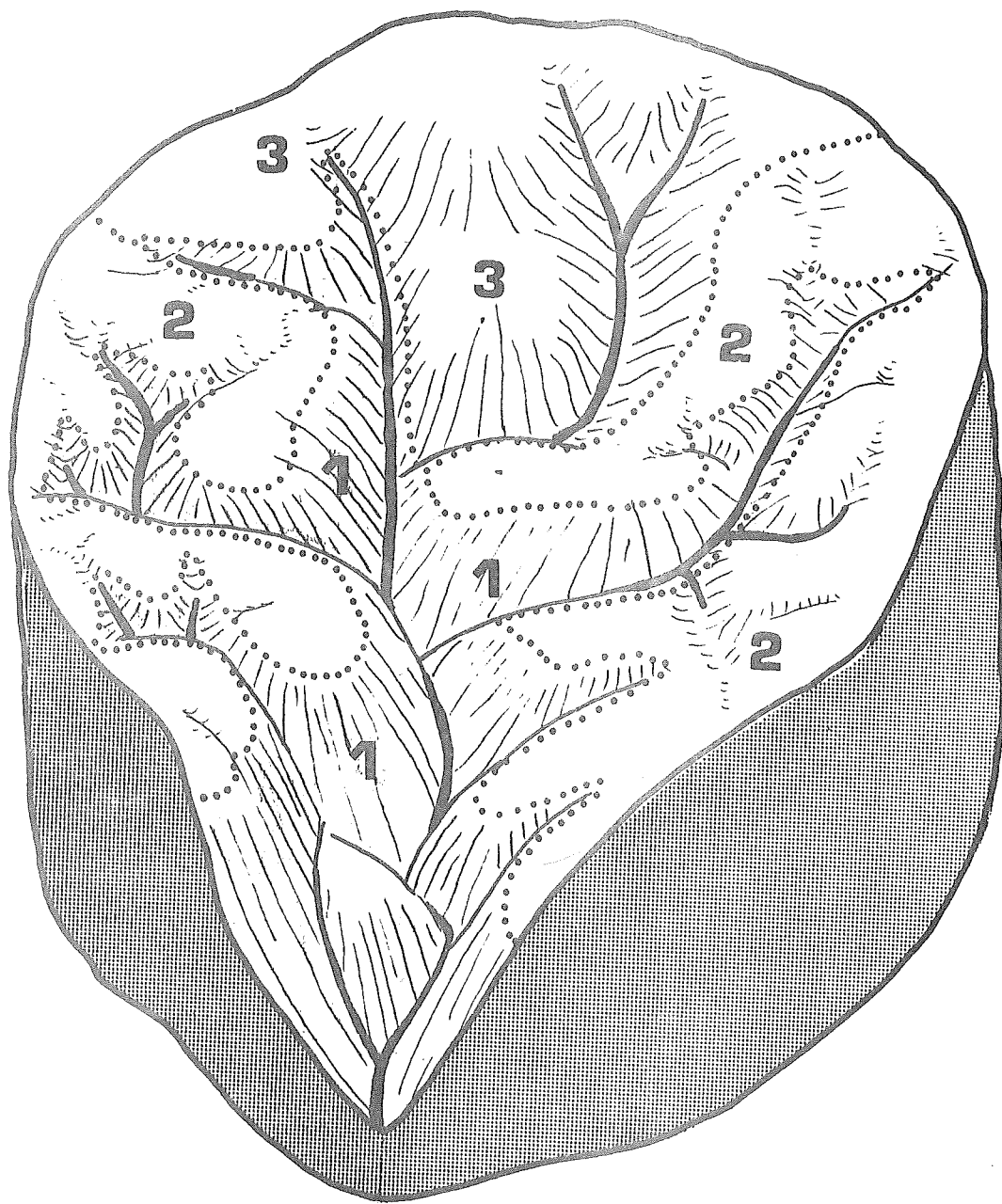
EXAMPLE

The following hypothetical example was selected to demonstrate the calculations necessary to properly apply the sediment yield model and to illustrate several possible uses of the model.

Statement of Sample Problem: The Forest soil and water specialists have been asked to predict sediment yields from a 15 square mile watershed. The mouth of the watershed has been identified as a critical reach by the Forest fishery biologist. Management would like to harvest timber in this previously undisturbed watershed. To complicate matters, a wildfire has just burned almost two square miles of the watershed. To simplify the analysis, it is assumed that logging and road construction are scheduled to begin the same season the fire took place. A management constraint on proposed activities has been previously identified which states that any sediment yield increase for this watershed must be held to less than 150 percent as measured at the critical reach. The Forest Supervisor has further stated that the timber from this area is vital to meeting Forest timber targets. Management wants an estimate of sediment yield from this watershed under natural conditions, under present conditions (with the wildfire), and for proposed conditions (fire plus road construction and logging) for each year of a 5-year planning period. Is the proposed management acceptable, given the above constraints? If not, what are some possible alternatives given that "don't cut the timber" is not an acceptable solution?

A relief sketch of the example watershed, including delineation of landtypes, is shown as Figure 6. Figure 7 shows a map of the same watershed with the proposed system roads, timber sale areas, and burned area. Additional basic information about these activities is also included.

In this example, sediment yield, due to mass erosion, is assumed insignificant and will not be considered. If mass erosion is important, the procedure in WRENSS should be followed and adapted to local conditions. This example will only concern itself with the calculation of natural sediment yield and sediment yield due to management-induced surface erosion. A further assumption will be made that, for the example, no local data is available and, consequently, all values used are as found in this guide. In most instances, Forests will have some data on hand and are encouraged to modify factors to local conditions.

This example consists of determining three kinds of sediment yields: (1) Natural sediment yield; (2) Sediment yield under present management; and (3) Sediment yield under proposed management. Interpretation of model outputs will be briefly discussed at the end of the example. Common data needs for the various portions of the model will be discussed first.

Figure 6: Relief sketch of example watershed showing landtypes.

TIMBER SALE AREA B (3.33 sq. miles)
 - Tractor Clearcut
 - Cutting units = 20% of sale area
                 = 0.67 sq. miles

BURNED AREA
(1.84 miles^2)

TIMBER SALE AREA A
(1.32 sq. miles)
 - Tractor Selection
 - Cutting units =
   20% of sale area
   = 0.26 sq. miles

WATERSHED AREA = 15 square miles
PARENT MATERIAL = Hard Sediments

CRITICAL STREAM REACH

SYSTEM ROADS = Standard 16 foot
 - Total length = 11.2 miles

MAP SCALE: 1 mile = 1.2 inches

0          $\frac{1}{2}$ 1 mile   2

Figure 7. Map of example watershed.

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Common Data Needs

The following data is needed for various portions of the model. This data is aggregated by land units (landtypes in our example) and presented in Table 7.

Table 7 — Common data needed for more than one part of the sediment model.

Land Unit (Landtype) (LT) Number	(1) Geologic Erosion Factor	(2) Mass Erosion Hazard Rating	(3) Average Slope (%)	(4) Land Unit Slope Factor	(5) Slope Sediment Delivery Ratio
1	0.52	40	70	1.81	0.60
2	0.52	18	25	0.70	0.15
3	0.52	25	40	0.96	0.20

Column

1 Geologic erosion factor. Parent material bedrock for the example watershed is assumed to be hard sediment. The geologic erosion factor from Table 2 for hard sediment is 0.52.

2 Mass erosion hazard ratings are determined according to procedures in WRENSS, Chapter 5.   Assumed mass erosion hazard ratings for the landtypes in the example are given in the table.

3 Average slope is the average slope of each landtype as determined from the land systems inventory.

4 The land unit slope factor is calculated using equation (1) in the text. The calculation for landtype (LT) 1 is as follows:

$$\text{Land Unit Slope Factor} = \frac{((0.43 + (0.30)(70) + (0.043)(70)(70) \times 0.0374)}{6.613} + 0.50$$

$$= 1.81 \quad (70 \text{ in the above equation is the average slope})$$

5 Slope sediment delivery ratios are determined using the procedure in WRENSS, Chapter 4.   Assumed slope sediment delivery ratios for the landtypes in this example are given in the table.

NATURAL SEDIMENT YIELD

The data that must be tabulated to calculate natural sediment yield is given in Table 8. Refer to Figure 2 for a flow chart of the procedure.

Table 8 - Data needed to calculate natural sediment yield.

Landtype Number	(1) Landtype Area (mi^2)	(2) Mass Erosion Hazard Rating	(3) Average Natural Sed. Rate (T/mi^2/yr)	(4) Land Unit Natural Sediment (T/yr)
1	6.51	40	41	266.9
2	4.62	18	12	55.4
3	3.87	25	15	58.0
Totals	15.00			380.3

Column

1 The area of each landtype is determined from the map (Figure 7).

2 Mass erosion hazard rating determined as explained under Table 7.

3 Average natural sediment rate can be determined in one of two ways:
   Option 1: Develop estimate for each landtype on the Forest based on local data and local expertise or USLE. Document procedure used.
   Option 2: Use relationship between mass erosion hazard rating and average natural sediment rate given in Figure 3. For LT#1, mass erosion hazard rating equals 40. Entering Figure 3, 40 on the x-axis results in a value of 41 on the y-axis as the average natural sediment rate.

4 Land unit natural sediment = (Avg. nat. sed. rate) (LT Area)
   LT#1: (41 T/mi^2/yr) (6.51 mi^2) = 266.9 T/yr
   LT#2: (12 T/mi^2/yr) (4.62 mi^2) = 54.4 T/yr
   LT#3: (15 T/mi^2/yr) (3.87 mi^2) = 58.0 T/yr
                                            380.3 T/yr = total for all landtypes

   Convert to unit area basis:
   $$\frac{\text{(Total land unit nat. sediment)}}{\text{Total watershed area}} = \frac{380.3 \text{ T/yr}}{15 \text{ mi}^2} = 25.4 \text{ T/mi}^2/\text{yr}$$

   Route sediment to critical reach:
   Use Figure 5 to obtain the channel sediment routing coefficient. For a drainage area of 15 sq. miles, enter the x-axis at 15 and read y-axis as a channel sediment routing coefficient of 0.61.

   Watershed Natural Sediment Yield = (total land unit natural sediment) times (channel sediment routing coefficient)
                                     = (25.4 T/mi^2/yr)(0.61) = 15.5 T/mi^2/yr
The natural sediment yield for the 15 sq. mile example watershed is 15.5 T/mi^2/yr.

SEDIMENT YIELD UNDER PRESENT MANAGEMENT

The example watershed is assumed to have been undisturbed by man's activities until the occurrence of the fire. Present sediment yield, therefore, consists of natural sediment yield plus any sediment yield increase due to the wildfire.

The data that must be tabulated to calculate sediment yield for the present condition of the watershed is given in Table 9. Refer to Figure 2 for a flow chart of the procedures for fire.

Table 9 - Data needed to calculate sediment yield under present management.

Landtype Number	(1) Basic Fire Erosion Rate $(T/mi^2/yr)$	(2) Disturbed Area (mi^2)	(3) Fire Intensity Class % of total area			(4) Average Fire Intensity Factor	(5) Total Fire Erosion (T/yr)	(6) Delivered Sediment (T/yr)
			High	Med	Low			
1	550	0.94	20	80	—	0.60	292.0	175.2
2	550	0.90	10	50	40	0.43	77.5	11.6
3	550	None	—	—	—	—		
Totals		1.84						186.8

Column

1   Basic fire erosion rates are obtained from Table 3. Since this is the first year after the fire, the value 550 $T/mi^2/yr$ is used.

2   The area disturbed by fire within each landtype is obtained from the map Figure 7).

3   Fire intensity class is expressed as a percent of the total disturbed area in each landtype that falls within each of the three fire intensity classes. Fire intensity classes are defined in Table 5. Values in Table 9 were assumed for this example.

4   The average fire intensity factor is calculated for each landtype by weighting according to the percent of area in each class. Fire intensity factors are found in Table 5.
Av. fire intensity factor = (High fire intensity factor)(% area burned)
        + (Med. fire intensity factor)(% area burned)
        + (Low fire intensity factor)(% area burned)
Avg. fire intensity (LT#1) = (1.0)(0.20) + (0.5)(0.80) + (0.2)(0) = 0.60
Avg. fire intensity (LT#2) = (1.0)(0.10) + (0.5)(0.50) + (0.2)(0.40) = 0.43

5   Total fire erosion = (basic fire erosion rate) times (geologic erosion factor) times (land unit slope factor) times (fire intensity factor) times (disturbed area)
Total fire erosion (LT#1) = (550)(0.52)(1.81)(0.60)(0.94) = 292.0 T/yr
Total fire erosion (LT#2) = (550)(0.52)(0.70)(0.43)(0.90) = 77.5 T/yr

6   Delivered sediment = (total fire erosion)(slope sediment delivery ratio)
Delivered sediment (LT#1) = (292.0 T/yr)(0.60) = 175.2 T/yr
Delivered sediment (LT#2) = (77.5 T/yr)(0.15) = $\underline{11.6}$ T/yr

$$186.8 = \text{total delivered sediment}$$

Convert to unit area basis: $\dfrac{\text{Total delivered sediment}}{\text{Total watershed area}}$ $= \dfrac{186.8 \text{ T/yr}}{15 \text{ sq. mi.}}$

$$= 12.5 \text{ T/mi}^2/\text{yr}$$

Route sediment to critical reach:
Channel sediment routing coefficient for 15 sq. mile watershed = 0.61
as determined from Figure 5.

Sediment yield due to fire = (total delivered sediment) times
                                  (channel sediment routing coefficient)
                              = (12.5 T/mi^2/yr)(0.61) = 7.6 T/mi^2/yr

Year 1 sediment yield due to fire = 7.6 T/mi^2/yr. Year 2 sediment yield due to fire is calculated by substituting the year 2 basic fire erosion rate into the equation used to calculate column 5. Since only one factor changes, total sediment yield for year 2 can be quickly calculated as a ratio of year 2 basic fire erosion rate to the base year 1 basic fire erosion rate. As an example, year 1 basic fire erosion rate = 550; year 2 basic fire erosion rate = 120. Year 2 divided by year 1 (120/550) shows year 2 to be 21.8 percent of the base year. Multiplying the year 1 sediment yield due to fire (7.6) by 21.8 percent results in the year 2 sediment yield due to fire (7.6 x 0.218 = 1.7 T/mi^2/yr). Total sediment yield due to fire for years 3,4, and 5 can be calculated in a similar manner assuming that only one factor in the equation's changes.

Total sediment yield = (Natural sediment yield) + (Sediment yield due to fire) for each year in the planning cycle. The results of these calculations for all years are shown in Table 10.

Table 10 - Sediment yield under present management for a 5-year period.

Year	Natural Sediment Yield (T/mi^2/yr)	Sediment Yield Due to Fire (T/mi^2/yr)	Present Condition Total Sed. Yield (T/mi^2/yr)	Increase Over Natural (%)
1	15.5	7.6	23.1	49
2	15.5	1.7	17.2	11
3	15.5	0.3	15.8	2
4	15.5	0.1	15.6	1
5	15.5	0.0	15.5	0

Sediment yield increase over natural was calculated using equation 5b in the text.

SEDIMENT YIELD UNDER PROPOSED MANAGEMENT

Proposed management for the example watershed is to consist of two planned timber sales and the construction of one road. For the sake of simplicity to assist in explaining the calculation procedure, road construction and the two timber sales are assumed to take place in the same year. Similarly, sediment yield impacts due to fire are also assumed to occur during this year and must be added to sediment yield calculated for the proposed management since they occur simultaneously on the watershed.

Sediment yield will be calculated first for the roads and then for the logging. The data that must be tabulated to calculate sediment yield for proposed roading is given in Table 11. Refer to Figure 2 for a flow chart at the procedure.

Table 11 — Data needed to calculate sediment yield under proposed management — roads.

Landtype Number	(1) Basic Road Erosion Rate ($T/mi^2/yr$)	(2) Road Length (miles)	(3) Width of Disturbed Area (feet)	(4) Width of Disturbed Area (miles)	(5) Disturbed Area (mi^2)	(6) Mitigation Factor
1	67,500	3.4	50	0.00947	0.032	0.60
2	67,500	5.9	23	0.00436	0.026	0.58
3	67,500	1.9	27	0.00511	0.010	0.58

Landtype Number	(7) Total Road Erosion (T/yr)	(8) Delivered Sediment (T/yr)
1	673.9	404.3
2	529.3	79.4
3	203.6	40.7
Total		524.4

Column

1   Basic road erosion rates are obtained from Table 3.

2   Road length is obtained from the map (Figure 7).

3   Width of the disturbed area is the horizontal distance from the top of the cut slope to the bottom of the fill slope. Tables of geometry, such as provided by Megahan (1976), are useful for making this determination. A standard 16-foot road is assumed with balanced construction, fill slope gradient of 1.5:1 and cut slope gradient of 1:1. Using the average slope for the landtype, geometry tables can be entered

directly to obtain the disturbed width. This was done for landtypes 2 and 3. An alternate method is to use geometric relationships to calculate these values. For landtype 1 (average slope 70%), the standard road assumed above was not felt to be realistic due to long fill slopes. Consequently, full bench construction with end-haul of materials was assumed for roads on this landtype. Consequently, only the width disturbed by the road surface and the cut slope were used to calculate width.

4   The width of the disturbed area in feet is converted to width in miles for ease of subsequent calculations (feet divided by 5280 feet/mile).

5   Disturbed area = (road length)(width of disturbed area)
Disturbed area (LT#1) = (3.4 miles)(0.00947 miles) = 0.032 sq. miles
Disturbed area (LT#2) = (5.9 miles)(0.00436 miles) = 0.026 sq. miles
Disturbed area (LT#3) = (1.9 miles)(0.00511 miles) = 0.010 sq. miles

6   Assumed mitigation measures to be applied to all roads are seeding and fertilization of all cut and fill slopes and planning for adequate buffer strips. In addition, roads in landtypes 2 and 3 are assumed to have grades less than 5 percent on the average. Percent erosion reduction for these measures are obtained from Table 4.

         Seed and fertilizer application   25% erosion reduction
         Buffer strips   15% erosion reduction
         Grades less than 5%   2% erosion reduction

The mitigation factor is the sum of the percent reduction in erosion for all mitigation measures applied subtracted from 1.0.
Mitigation factor (LT#1) = 1.0 - (0.25 + 0.15) = 1.0 - 0.40 = 0.60
Mitigation factor (LT#2) = 1.0 - (0.25 + 0.15 + 0.02) = 0.58
Mitigation factor (LT#3) = 1.0 - (0.25 + 0.15 + 0.02) = 0.58

7   Total road erosion = (basic road erosion rate) times (geologic erosion factor) times (disturbed area) times (mitigation factor)
Total road erosion (LT#1) = (67,500)(0.52)(0.032)(0.60) = 673.9 T/yr
Total road erosion (LT#2) = (67,500)(0.52)(0.026)(0.58) = 529.3 T/yr
Total road erosion (LT#3) = (67,500)(0.52)(0.010)(0.58) = 203.6 T/yr

8   Delivered sediment = (total road erosion)(slope sediment delivery ratio)
Delivered sediment (LT#1) = (673.9 T/yr)(0.60) = 404.3 T/yr
Delivered sediment (LT#2) = (529.3 T/yr)(0.15) = 79.4 T/yr
Delivered sediment (LT#3) = (203.6 T/yr)(0.20) = 40.7 T/yr
                                                   524.4 T/yr = total delivered sediment

Convert to unit area basis: $\dfrac{\text{Total delivered sediment}}{\text{Total watershed area}} = \dfrac{524.4 \text{ T/yr}}{15 \text{ sq. mi.}}$

$$= 35.0 \text{ T/mi}^2/\text{yr}$$

Route to critical reach:
Channel sediment routing coefficient = 0.61 (see Figure 5)
Sediment yield due to roads = (total sediment delivered) times (channel sediment routing coefficient)
$$= (35.0 \text{ T/mi}^2/\text{yr})(0.61) = 21.4 \text{ T/mi}^2/\text{yr}$$

Year 1 sediment yield due to roads = 21.4 $T/mi^2/yr$.
Year 2 sediment yield due to roads is calculated by substituting the year 2
basic road erosion rate into the equation used to calculate Column 7 and then
performing the remaining calculations as demonstrated. An alternate quick
method is to use the ratio procedure as described for fire in the previous
section.
Year 2 sediment due to roads = 18,000/67,500 = 26.7 percent and 26.7 percent
of 21.4 = 5.7 $T/mi^2/yr$.
Total sediment yield due to roads for years 3, 4, and 5 are calculated in a
similar manner, assuming only the basic road erosion rate factor changes. If
other factors, such as mitigation measures, also change, the long procedure
should be used. Total sediment yield due to roads for subsequent years will
be displayed after the discussion of logging.

The data that must be tabulated to calculate sediment yield due to proposed
logging is given in Table 12.

Table 12 - Data needed to calculate sediment yield under proposed management
- logging.

Landtype Number	(1) Timber Sale Area	(2) Logging System Erosion Factor	(3) Total Sale Area (mi²)	(4) Disturbed Area (mi²)	(5) Basic Logging Erosion Rate (T/mi²/yr)	(6) Total Logging Erosion (T/yr)	(7) Delivered Sediment (T/yr)
1	B	1.00	0.13	0.03	340	9.6	5.8
2	A	0.71	1.32	0.26	340	22.8	3.4
3	B	1.00	3.20	0.64	340	108.6	21.7
Total							30.9

Column

1   Timber sale areas are defined in Figure 7.

2   Logging system erosion factors are obtained from Table 6. Sale area A
     is assumed clearcut tractor selection; sale area B is assumed clearcut
     tractor.

3   The total sale area in each landtype is obtained from the map (Figure 7).

4   The area actually disturbed by logging operations and temporary roads
     is the area within timber sale boundaries composed of cutting units and
     temporary roads. For this example, cutting units were assumed to be 20
     percent of the total sale area.

5   Basic logging erosion rates are taken from year 1 of Table 3.

6   Total logging erosion = (basic logging erosion rate) times (geologic
erosion factor) times (land unit slope factor)
times (logging system factor) times (disturbed
area)

Total logging erosion (LT#1) = (340)(0.52)(1.81)(1.00)(0.03) = 9.6 T/yr
Total logging erosion (LT#2) = (340)(0.52)(0.70)(0.71)(0.26) = 22.8 T/yr
Total logging erosion (LT#3) = (340)(0.52)(0.96)(1.00)(0.64) = 108.6 T/yr

7   Delivered sediment = (total logging erosion)(slope sediment delivery ratio)
Delivered sediment (LT#1) = (9.6 T/yr)(0.60) = 5.8 T/yr
Delivered sediment (LT#2) = (22.8 T/yr)(0.15) = 3.4 T/yr
Delivered sediment (LT#3) = (108.6 T/yr)(0.20) = 21.7 T/yr
                                                  30.9 T/yr = total delivered
                                                            sediment

Convert to unit area basis: $\dfrac{\text{Total delivered sediment}}{\text{Total watershed area}} = \dfrac{30.9 \text{ T/yr}}{15 \text{ sq. mi.}}$

$$= 2.1 \text{ T/mi}^2/\text{yr}$$

Route to critical reach:
Channel sediment routing coefficient = 0.61 (see Figure 5)
Sediment yield due to logging = (total sediment delivered) times
(channel sediment routing coefficient)
$$= (2.1 \text{ T/mi}^2/\text{yr})(0.61) = 1.3 \text{ T/mi}^2/\text{yr}$$

Year 1 sediment yield due to logging = 1.3 T/mi^2/yr.
Year 2 sediment yield due to logging is calculated by substituting the
year 2 basic logging erosion rate into the equation used to calculate
column 6 and then performing the remaining calculations as
demonstrated.
An alternate quick method is to use the ratio procedure as described
for fire in the sediment yield under the present management section.
Year 2 sediment due to logging = 180/340 = 52.9% and 52.9% of 1.3 = 0.7
                                                                  T/mi^2/yr.

Total sediment yield due to logging for years 3, 4, and 5 are
calculated in a similar manner assuming only the basic logging erosion
rate factor changes.

Proposed Management:
Total sediment yield = (Natural sediment yield) + (Sediment due to
management-induced surface erosion)
= Natural sediment yield) + (Sediment due to roads) +
(Sediment due to logging) + (Sediment due to fire)
Total Sed. Yield (Year 1) = (15.5) + (21.4) + (1.3) + (7.6) = 45.8 T/mi^2/yr.

Percent increase in sediment yield over natural is calculated according to
equation 5b in the text. For year 1:
Percent increase over natural = $\left(\dfrac{(15.5) + (21.4) + (1.3) + (7.6)}{15.5} \times 100\right) - 100$

$$= 195 \text{ percent}$$

The results of all these calculations for all 5 years are presented in
Table 13.

Table 13 — Sediment yield under proposed management for a 5-year period.

Year	Natural Sed. Yield (T/mi^2/yr)	Management-Induced Sed. (T/mi^2/yr)			Total Sediment Yield (T/mi^2/yr)	Increase Over Natural (Percent)
		Roads	Logging	Fire		
1	15.5	21.4	1.3	7.6	45.8	195
2	15.5	5.7	0.7	1.7	23.6	52
3	15.5	1.6	0.5	0.3	17.9	15
4	15.5	1.6	0.3	0.1	17.5	13
5	15.5	1.6	0.2	0.0	17.3	12

Interpretations: Year 1 total sediment yield is predicted to be greater than the 150 percent increase over natural which is considered the acceptable level of increase for the purposes of this example. Comparing sediment yield estimates in Table 13, it is readily apparent that roads contribute the greatest amount of sediment and that sediment yields decrease rapidly over time. Consequently, two approaches to reducing sediment yields are possible. One is to modify activities, especially during the first year, to reduce sediment yields; the other is to spread sediment yields over a longer time period.

One possible alternative is to increase mitigation measures on the road system until acceptable total sediment yield increases are achieved. By maximizing mitigation measures to 80 percent, percent increase over natural can be reduced to 104 percent. Using the other approach of spreading impacts over time, road construction could be staged over several years as could the logging. Numerous other alternatives can be developed and evaluated such as changing road design, investigating alternate road locations, using different harvesting systems, deferring entry until fire effects are reduced, or combinations of the above.

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APPENDIX A: GLOSSARY

Bedload - Material moving on or near the streambed by rolling, sliding, and, sometimes, making brief excursions into the flow a few diameters above the bed.

Critical stream reach - A reach of the stream that is selected because it is the point in the watershed where the importance of sediment yield will be interpreted.

Erosion - The wearing away of the land surface by detachment and movement of soil and rock fragments through the action of moving water and other geologic agents.

The following terms are used to describe different types of erosion:

Accelerated erosion - Erosion, at a rate greater than normal, is usually associated with the activities of man which reduce plant cover and increase runoff. Accelerated erosion is discussed as management-induced surface erosion and management-induced mass erosion.

Natural erosion - The erosion process, on a given land form, that is not associated with the activities of man. Natural erosion delivered downstream results in what is referred to as natural sediment yield.

Mass erosion - Movement of large masses of earth materials in response to gravity, either slowly or quickly. This includeds, slumps - rotation of a soil block with small lateral displacement, debris avalanches - rapid, shallow movement of soil mantle and rock fragments, landslides - sudden downslope movement of earth and rock, and soil creep - slow, gradual, more or less continuous permanent deformation of soil under gravitational stress.

Surface erosion - The wearing away of the land surface by running water or wind. This includes: sheet erosion, the removal of a surface soil by runoff water; rainsplash erosion, the spattering of small soil particles caused by the impact of raindrops on the soil surface; and rill and gully erosion.

Land unit - The basic area of land displaying relatively uniform characteristics and defined in a manner to provide necessary physical information needed to drive the model. Landtypes in the land systems inventory, generally, provide this kind of information.

Logging systems - The following definitions are used for these logging systems:

Tractor refers to tractors working directly on-site.

Cable refers to ground cable systems where logs are dragged without suspension, including jammer and high lead systems.

Skyline refers to suspended cable systems that allow at least partial log suspension for all or part of the yarding distance.

Aerial refers to aerial systems (helicopter or balloon) that allow for essentially complete log suspension.

Routing - (1) The derivation of an outflow hydrograph of a stream from known values of upstream inflow. (2) Computing the flood at a downstream point from the flood inflow at an upstream point, and taking channel storage into account.

Sediment - Particles derived from rocks or biological materials that have been transported by a fluid.

Sediment delivery - Two types of sediment delivery are discussed. 1) slope sediment delivery is the material brought to the stream channel from surrounding hillslopes by surface and mass erosion, and 2) channel sediment delivery is the movement of sediment through the stream channel system in response to stream hydraulics.

Sediment delivery ratio - The volume of sediment material actually delivered to a point in a watershed divided by the total amount of material available for delivery. Two types of delivery ratios are discussed: (1) slope sediment delivery ratio, and (2) channel sediment routing coefficient as respectively discussed under sediment delivery above.

Sediment routing - (1) The process of determining progressively the timing and shape of a sediment wave at successive points along a river; (2) term used to discuss the movement of sediment within a stream channel system.

Sediment yield - The total sediment outflow from a drainage basin in a specified period of time. It includes bedload as well as suspended load, and is expressed in terms of mass, or volume per unit of time. The standard unit of expression for our purpose is tons/square mile/year.

Suspended sediment - Sediment that is carried in suspension by the turbulent components of the fluid or Brownian movement.

Total sediment load - All of the sediment in transport; that part moving as suspended load plus that part moving as bedload.

APPENDIX B: DESCRIPTION OF BOISE NATIONAL FOREST LANDTYPES
(corresponds to 25 T/mi^2/yr natural sediment yield)

Map Symbol 120c
STRONGLY DISSECTED MOUNTAIN SLOPE LANDS
Shallow and Moderately Deep Sandy and Sandy Skeletal Soils Over Soft Bedrock

Location: This unit is common along Lick Creek and around the Deadwood
Reservoir.

Landtype Characteristic: These lands are steep southerly slopes that have been
deeply incised by a stream cutting. Side slopes have numerous dendritic
dissections 30 to over 50 feet deep and less than 500 feet apart. In areas
where dissections are more widely spaced, entrenchment is deeper. Slope
gradients range from 40 to 70 percent. Ridges are relatively sharp with little
exposed bedrock. The slopes are moderately well timbered with forest crown
densities ranging from 10 to 60 percent. The shallow and moderately deep sandy
and sandy skeletal soils are underlain by moderately to well weathered granite
that is extremely well fractured or masked.

Soils: The dominant soil (80%--JEFA-1), on most mid and lower slopes, has a
0 to 1-inch organic layer over a brown gravelly sand, 20 to 60 inches deep,
with 20 percent fine gravels. A minor soil (20%--JEFA-2) is a shallow phase of
the dominant soil and contains 40 percent coarse fragments dominated by fine
gravels.

Vegetation: The slopes of this landtype are moderately timbered with the
following habitat types represented: Douglas-fir/spirea, Douglas-fir/wheat
grass, Douglas-fir/pinegrass, Douglas-fir/ninebark, and ponderosa pine/bitter-
brush. Forest crown density is 10 to 60 percent and brush crown density is 40
to 70 percent.

Hydrology: Mean annual precipitation is 20 to 35 inches and mean water yield
is 5 to 15 inches. Snowpacks are low to moderate and snowmelt can occur on and
off in late winter on southerly aspects. Runoff is usually spread over a three
to four-month period ending in mid to late May. Runoff from normal snowmelt
conditions is shallow to moderately deep subsurface flow and deep percolation
through the soft bedrock. These areas receive 8 to 15 inches of water input
from heavy rainstorms and rain-on-snow events on an average of about once in
ten years. Under these conditions, heavy runoff occurs in a few days
dominantly as shallow subsurface flow which accumulates in concave incipient
draws and moves down these draws until forced to the surface. These slopes
release the water delivered to them at a moderate to rapid rate and dry rapidly
after snowmelt. Water held in weathered bedrock provides much of the summer
moisture for deep rooted vegetation.

Management Qualities: Construction hazards are rated dominantly high on this
landtype. Interception of subsurface flow, spalling bedrock, and sedimentation
are the most important considerations.

Roads. The characteristics of this landtype are generally poor for road
location except on upper slopes and ridges. Poorly graded, incompetent,

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spalling bedrock, combined with the probable interception of subsurface flow on lower slopes, will result in unstable cuts and fills. These factors will increase the probability that sediment will reach adjacent drainages. Accelerated surface erosion will be a major problem fror disturbed soil surfaces and construction.

Wood. These units are some of the more productive on the District. The timber productivity rating is dominantly moderate with ponderosa pine; the most productive seral species of the Douglas-fir habitat types. Limitations to reforestation are severe and are related to water holding capacity and high evapotranspiration losses.

Water. Interception of subsurface flow is a moderate hazard in normal runoff years because runoff is spread over a number of months. However, during the abnormally heavy rains and rain-on-snow events, which can occur in fall, winter or spring, subsurface flow interception and concentration is a very serious hazard because of the large amount of runoff during a short period. The hazard for serious erosion and sedimentation from concentration of intercepted subsurface flow during these periods is very high. A combination of moderately deep cuts and disturbed soil near drainage channels will increase the hazard for serious sedimentation. Road crossings of the deeply entrenched second and third order streams have a high sedimentation hazard. The convex upper slopes are less hazardous due to the lack of deeply entrenched drainage channels and less accumulated subsurface runoff water.

Forage. The potential production for this landtype is 400 to 900 pounds per acre per year of usable dry forage. The lower yield is associated with the exposed upper ridge positions and the shallow, coarse-textured soils. On these areas, water holding capacity is low. The higher yields are related to the more moist micro-climate on protected lower slopes and drainages. The vegetation is dominated by browse species. Grasses and forbs are limited. Grazing, however, will greatly accelerate the erosional process by removing the protective vegetation and litter. Surface creep hazard will also be accentuated.

Recreation. The potential for recreation on these units are related to aesthetics and providing a "Forest Experience." The landtype provides a timbered scenic backdrop for vistas but is generally unstable for most recreational developments and roads. Big game hunting is a major fall activity on these units. Trails will be highly erosive but have fair to good trafficability.

Map Symbol 120c-11
STRONGLY DIESSECTED MOUNTAIN SLOPE LAND
Moderately Deep and Deep Fine Loamy and Loamy Skeletal Soil

Location: This landtype is common to those heavily timbered steep north slopes over most of the District. The north slopes above the Middle Fork of the Payette River are typical.

Landtype Characteristics: These fluvial lands are the steep north slopes that
have been strongly (less than 500 feet apart) incised by stream cutting,
intermittent concentrations of overland flow and the rapid concentration of
shallow and moderately deep subsurface flow. Sideslopes are of moderate length
and steep with numerous parallel dissections. Ridges are relatively sharp with
little exposed bedrock. Slope gradients range from 50 to 70 percent. The
moderately deep and deep coarse loamy and loamy skeletal soils have developed
over masked or well fractured, moderately to well weathered granite bedrock.

Soils: The dominant soil (60%--IFBA-5) has a 0 to 4-inch organic layer over a
dark brown to dark yellowish brown gravelly sandy loam 40 to 60 inches deep,
with 25 percent fine gravel, and 20 to 30 percent rock. This soil is most
common on mid and upper slopes. A less extensive soil (40%--IFBA-3) on more
exposed upper east and west slopes and areas of highly weathered granite on
north slopes, has a 0 to 3-inch organic layer over a very dark grayish brown to
dark brown gravelly sandy loam to gravelly loamy coarse sand, 20 to 60 inches
deep, with 10 to 20 percent fine gravels and less than 10 percent rock.

Vegetation: This landtype is one of the better timber producing units on the
District with forest crown densities ranging from 30 to 80 percent. The
dominant habitat types are ponderosa pine/wheatgrass, Douglas-fir/chokecherry,
Douglas-fir/spiraea, and Douglas-fir/ninebark. Brush crown densities range
from 30 to 80 percent.

Hydrology: Mean annual precipitation is 28 to 40 inches and mean water yield
is 10 to 20 inches. Snowpack is moderate to heavy and persists into June on
the highest areas and into May on the lower areas. Major runoff is in April
and May when heavy discharge of subsurface flow occurs. Overland flow from
summer storms is rare on undisturbed areas. Runoff is about evenly divided
between moderately deep subsurface flow above bedrock and ground-water flow
through the upper weathered and fractured portion of bedrock. The accumulation
of this runoff increases going downslope and moving from convex to straight to
concave shaped slopes. Greatest concentration of subsurface flow is in the
incipient drainageways on the lower two-thirds of the slope. Ground-water is
most concentrated and nearest the surface on deep soiled slopes and deposits
adjacent to the more deeply entrenched streams. Debris-laden flash flows
seldom occur in drainageways in this landtype. Outflow rate of water delivered
to these slopes is slow to moderate.

Management Qualities: Most hazards for this landtype are rated moderate to
very high. High surface erosion hazards and mass stability problems associated
with interception of subsurface flow will be major limitations. Bedrock
spalling will be common in most exposed road cuts. This landtype, however, is
one of the most productive for commercial timber species.

> Roads. The qualities of this landtype present many hazards to road
> construction. Very poorly graded, noncompetent, spalling bedrock combined
> with probable interception of subsurface flow will result in very unstable
> road cuts and fills. These problems combine with a high surface erosion
> hazard greatly increasing the probability that sediment will reach
> adjacent drainages. The least impact has been observed where roads have
> been restricted to the upper one-quarter of slopes althogh surface erosion
> and interception of subsurface water are still problems in selected areas.

Some areas of very well weathered granite bedrock, clay pockets, are of limited extent but very significant because of the problems they create in construction. These heavy textured soils are restricted to the more moist northerly aspects that are heavily vegetated. Where possible, these areas should be avoided.

Wood. This landtype is one of the better commercial timber producing units on the District. Timber productivity ratings range dominantly from moderate to very high for the major habitat types, Douglas-fir/spirea and Douglas-fir/ninebark. Reforestation site limitations are moderate to severe with high evapotranspiration losses on south slopes and vegetative competition on all slopes the major limiting factors.

Water. Hazard of intercepting large quantities of subsurface flow is hgih at concave swales and incipient draws. Hazard of ground-water interception is high adjacent to streams. Sedimentation hazard is high to very high for roads crossing the deeply entrenched streams on the lower one-half of these slopes and moderate to high on the upper one-half. The combination of hazards presents an overall hazard to hydrologic characteristics of high to very high on lower slopes and moderate to high on upper slopes.

Forage. Forage production potential on this landtype is rated low to high with the vegetation dominated by browse species. Grasses and forbs are limited, most common under the ponderosa pine habitat types on southerly ascpects. Grazing, however, will greatly accelerate the erosional processes by removing the protective vegetation and litter. Surface creep will also be accelerated increasing the frequency of debris slides.

APPENDIX

Forest Service Response to Review Comments

Made by Potlatch Corporation.

Federal Building
P.O. Box 7669
Missoula, MT 59807

2500

JUN 30 1982

Potlatch Corporation
ATTN: Dale J. McGreer, Forest Hydrologist
P.O. Box 1016
Lewiston, ID 83501

Re: Your 11/16/81, comments on the Region 1 and 4 Draft Guidelines for
  Predicting Sediment Yields.

Dear Mr. McGreer:

We have coordinated review comments to your suggestions, in the above-
mentioned document, with our Intermountain Station in Boise, ID, R-4, and
R-1, Clearwater National Forest offices. Enclosed is a compilation of
these comments.

Your comments concerning the Region 1 and 4 draft sediment prediction
guides were interesting and a number of good points were made. We agree
that the model provides a framework upon which more reliable models can be
developed. We are fully aware of the model's weaknesses and intend to
revise the model as more information from research and application in the
field becomes available. We are also in agreement that additional infor-
mation is desperately needed and that it can only be supplied by well
designed research. Much of the on-going Forest Service research at the
Silver Creek and Horse Creek studies is directed toward that end.

We appreciate the constructive criticism and would like to take this oppor-
tunity to thank you for your time and effort in critically reviewing the
sediment prediction guide. Your review has helped us reexamine important
model components and model usability. Feel free to contact us if you have
further concerns.

Sincerely,

/s/ Buster La-mowe

TOM COSTON
Regional Forester

Enclosure

The tone of the comments indicates a strong objection to use of the model and its stated value inputs in project applications. The procedure outlined is intended primarily for making relative comparisons of management alternatives. It is not intended as an absolute quantitative constraint mechanism. The concepts upon which the model is built are usable at the project level (objective 2, page 2), but application at this level of definition requires locally applicable data refinement and adaptation of model application techniques to fit local conditions (item 7, page 4). This kind of application requires considerable professional judgment on the part of the user and substantial refinement and testing of model inputs.

Point 1 is a valid point and no attempt was made to hide the crudeness of the estimate. The model requires a starting point if it is to work and recommends revision of method or use of better local data where it is available. The basic value (25 tons mi^{-2} $year^{-1}$) is well documented for the conditions stated. Dr. Megahan suggested that large deviations from this value should not be expected to result from changes in slope gradient in these granitic landscapes under undisturbed conditions. It seemed unreasonable, however, that there would be none, particularly with a reference slope gradient of 60 percent. It should be noted that a very logical, hence acceptable, modification to the model, in areas dominated by well developed glacial cirques in hard bedrock, would be to decrease sediment substantially even though slopes may be far in excess of 60 percent. This kind of modification to fit local conditions was intended.

Plotting sediment yields from the H.J. Andrews, Coyote Creek, and Flynn Creek areas in Oregon and areas in California on figure 3 is invalid. The curve was developed from Idaho batholith data and experience. The variability of Silver Creek data is large, as is most sediment data. We use the mean value, which is a standard technique. The Horse Creek watersheds are border granitics and are expected to have lower sediment yields. Figure 3 will be revised, if necessary, as more data become available.

Point 2 suggests the extrapolation of geologic erosion rates from another climatic zone is suspect. This is not a valid criticism. The method of adjusting surface erosion by geologic types is based solely upon the relative index of soil erodibility determined by the surface aggregation ratio (S/A). It is a direct indicator of surface erosion primarily indexing detachability. The reference by Andre' and Anderson describes the process used to develop the S/A ratio and how it might be applied to sedimentation studies. The research did not depend on relationships to total watershed erosion to develop the indices. The values in the literature agreed with our general field observations. For example, the hard metamorphic rocks of the Belt Super group of Western Montana produce soil materials which seem much less erodible than materials in the central Idaho Batholith. Table 2 suggests the relationship was something like 39 percent of that to be expected from granitics with about a 50 percent coefficient of variation on the absolute value. This seemed realistic and the coefficient of variation, derived from the original published data, is intended to indicate the degree of uncertainty one might expect in numerical application.

Point 3 is a true statement. The assumption is that stream channels in watersheds averaging 1 square mile in size are steep, high energy, first and second order channels capable of transporting all the sediment delivered to them. This would not be the case for cirque basins and alpine lake systems.

Point 4 is correct. The value chosen as a starting point is derived from resource data from the area which serves as a reference in the model. There doesn't seem to be any substantive disagreement on this issue. There are several statements in the model which suggest use of better local data where it is available. This seems to be the suggestion. The slope delivery coefficient may also be revised as more data become available.

The last statement on page 2 concerning how models should be developed may not be possible and is not always necessary given the purpose of the model. We do not have time for data to be collected in a modeling effort such as the one suggested. This is not, however, contrary to the scientific method. The scientific method is essentially an effort to disprove, not confirm. If one is to disprove something, there must be a hypothesis. This, at least in part, is one of the purposes of having a model. It provides a starting point which is subject to disproof and improvement. It has also served to identify several areas in need of research (i.e., landform-sediment delivery relationships, and our lack of knowledge concerning sediment routing in mountainous watersheds). It is not at all unusual in science to use working hypotheses while making every effort to modify them. They are simply the tools available at the time.

Point 5. Equation 2 in the guidelines is a difficult one to comprehend without considerable explanation. Anderson reports that 2 or 3 times as much sediment yield was measured from logged watersheds as from unlogged watersheds using a variety of logging systems. Using 2.5 times as a factor we get $2.5 \times 25 = 62.5$ tons as the sedimnt yield for year one. This is sediment measured at the mouths of study watersheds and includes natural sediment and delivered surface erosion. If natural sediment is subtracted: $62.5 - 25 = 37.5$ tons; this becomes the delivered accelerated sediment for year one. If the delivery coefficient is assumed to be 0.33 for the 37.5 tons of accelerated sediment, then $37.5/0.33 = 113.6$ tons is the accelerated on-site erosion. The 0.33 that appears in equation 2 is the factor used to convert 113.6 tons of erosion from skyline to tractor logging. Although not specifically stated, Anderson's data from W. Oregon probably represented cable logging on good ground, which we assumed to be equivalent to the skyline system of Megahan's studies. This results in a first year logging erosion rate of 340 tons/mi^2/yr. The integration of the resulting logarithmic recovery curve, when the values are converted back to a skyline system, yields an increase in sediment yield of 60 percent greater than a natural rate of 25 tons/year for the 6-year period, as found by Megahan and Kidd. A more conceptually correct form of equation 2 would conform to the statement:

$$\frac{\frac{(2.5 \times 25) - 25}{.33}}{.33} = 340$$

This agrees with the above discussion. The answer carries only the two significant figures indicated by the values used in calculatio .

Point 6 is correct. This assumption was stated. The other factors suggested certainly do affect erosion. Given the generality of the model, however, the amount of bare soil would seem the factor most influencing erosion. Items such as degree, depth and aerial distribution are likely to be quite site or even operator specific and, as a result, far more specific than expected model sensitivity.

Point 7 is correct. The method is untested. It is logical and seems the best available. It provides a workable approach in a general application. It also documents the procedure used. Again, as in any portion of the model, local data and more refined procedures which can be demonstrated to more specifically fit local conditions should be used. This was stated on page 1 in the executive summary.

The intent of the model is to provide a documentable basis for making comparisons of management alternatives. The example illustrates this and indicates (p. 38) how alternatives may be compared to give managers an impression of the general cost and effort required to implement decisions. The example is used only as a means to illustrate how the procedure works and to provide sample calculations for users to work through. Comments on the example suggest the use of a real example. This was never intended as few real examples provide a range of conditions suitable for illustrating a range of uses for the model.

Comments about recognition of the accelerated sediment delivery due to single debris avalanches are well taken. Conversations with Dr. Bill Platts indicate that salmonids do indeed survive these short duration, high intensity events very nicely. The real problem occurs when average sediment loads are elevated over longer periods as happened in the South Fork Salmon River drainage. This is one of the reasons annual averages are used in the model. A statement to this effect appeared in an earlier draft, but was lost in editing. This statement has been reincorporated in the October 1981 revision (p. 26). This difference in scale and perspective of model use has a significant effect on the applicability of the assumptions and procedures used to construct it. A more appropriate method of dealing with the mass failure problem in a model applied to large areas and long time periods is to develop estimates of probability of occurrence. Individual events at this scale are inappropriate. If correctly applied, the model should not be at all sensitive to a predicted single event.

The last statement in the letter suggests a heavy emphasis be placed on professional judgment and implies the model does not allow this emphasis. Application of this model, in fact, requires a large degree of professional judgment. Every step of the procedure requires the professional to test the model's assumptions against local conditions and every assumption and calculation is subject to modification to fit local conditions. The model provides only a framework to assure a consistently documented procedure. There are several statements to this effect in the draft and they have not been altered in the October 1981 revision.

November 16, 1981

RE: ....

NOV 1 : 198.

RANGE & WATERSHED MGMT.

Director
  Grp. Secty.
  Clerk
Rge. Admin.
  Syneco.
Rge. Imple.
  Techniques
Reg. H drologist
  H drologist
Reg. Soil Sch.
  Soil Sci.
Prog. Dev. & Budg.
  Rge. Prog. Asst.
  SAW Prog. Asst.
  Tech.

Mr. Tom Costin
Regional Forester
U.S. Forest Service
P.O. Box 7669
Missoula, Montana   59807

Dear Mr. Costin:

Reference 2500

Attached are detailed comments on the Region I and IV Draft
Guidelines for Predicting Sediment Yields. Please accept these
comments as being constructive, which is their intent.

Preparation of the R-I Guidelines clearly required a great deal
of effort. They are well written and the model outlined by
the Guidelines provides a logical means of segmenting complex
processes into components which when isolated can be comprehended,
examined and tested. This is most commendable.

In studying the Guidelines, I have looked at the application of
specific components, coefficients, and applicable published
literature.

Predictions of hydrologic impacts - and specifically those of
erosion and sedimentation - have the potential to affect utilization
of Forest timber resources more than any other single factor
within the planning process. If long-term optimum multiple
resource management justifies constraints based on hydrologic
and related impacts, so be it. However, if the constraints are
not justified, and in particular, not justified due to erroneous
constraints imposed by application of the Sediment Prediction
Methodology, those constraints and application of the Methodology
itself should be seriously re-examined.

You will note in the following comments that I have challenged
major elements of the Methodology. I am hopefull that this input
will stimulate honest re-examination of model elements and lead
to future improvements and will not serve to solidify a defensive
posture.

The model in its present early stage of validation provides a framework upon which more reliable models can be developed. It also provides an excellent means of identifying sections which are weak and needs for additional information – some of which in my view are desperately needed and can only be supplied by well-designed research.

The model may be at a stage which allows professionals to "flag" potential problems to themselves, to be followed by more careful examination. However, in my judgement, major model components and thus the model itself are demonstrably insufficiently accurate to be used as a basis for formulation of management decisions. I base this on the following summary of major weaknesses in the model.

1. The single most significant step within the Methodology requires prediction of natural sediment yields. There is no evidence that this can be done using this method.

a. The Mass Erosion Hazard Rating System has never been verified. (i.e., no one knows how well it predicts hazard.)

b. There is no relation of the above to annual sediment yield. i. The purported curvilinear relationship (line) was developed from a single data point (unpublished) and extended to two estimated "end points". ii. Reference to published literature demonstrates that no such relationship exists. (See Figure A, attached)
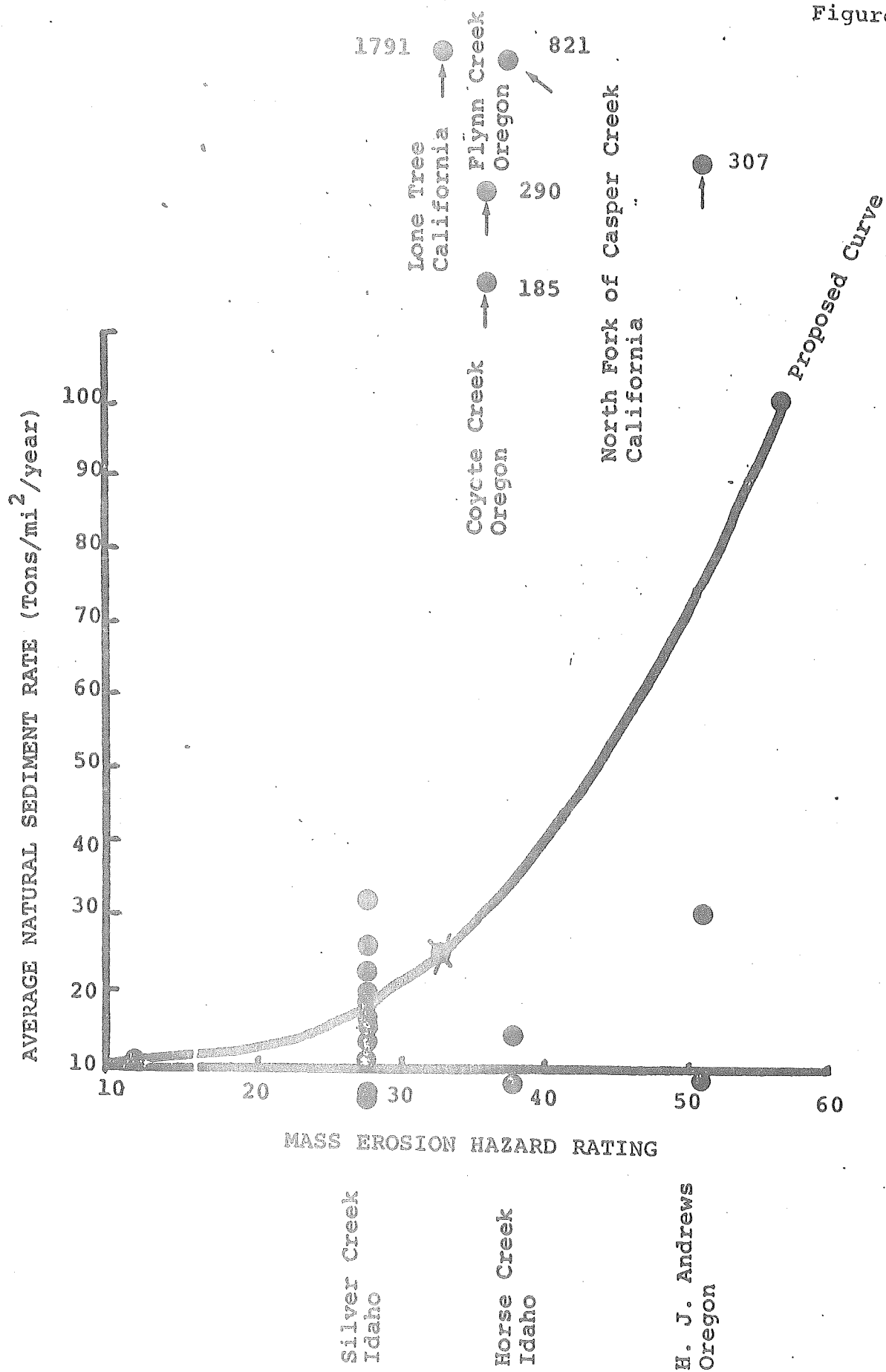
2. The method of adjusting surface erosion rates by geologic type is highly suspect. The research relied upon related surface soil characteristics by geologic type to total watershed erosion in Northern California and Coastal Oregon. There is no logical reason to believe that these factors are related to surface erosion in the Rocky Mountains.

3. The Guidelines assume that 100 percent of all sediment delivered to channels draining areas of less than one square mile will be transported downstream. This certainly may be true for steep high energy channels, and certainly not for channels with less transport capacity.

4. Delivery of erosion from areas disturbed by fire varies by slope within the model. However, the curvilinear delivery function was again developed with one data point, with estimated end points. The relationship is untested and thus there is no way of knowing its accuracy.

This (and point #3) raise the question of how models should be developed: data should be collected and a relationship fit to it as opposed to developing a relationship and subjectively evaluating how well it fits subsequently gathered data.

Figure A

AVERAGE NATURAL SEDIMENT RATE (Tons/mi^2/year)

MASS EROSION HAZARD RATING

Proposed Curve

1791

821

307

290

185

Lone Tree
California

Flynn Creek
Oregon

North Fork of Casper Creek
California

Coyote Creek
Oregon

Silver Creek
Idaho

Horse Creek
Idaho

H. J. Andrews
Oregon

100
90
80
70
60
50
40
30
20
10

10   20   30   40   50   60

5. The calculation of on-site natural erosion per Equation 2 does not appear to mathematically correctly reflect process, and if so, overestimates natural on-site erosion by a factor of nearly 2.

6. A 1 to 1 relationship is assumed between soil exposed by different logging methods and erosion produced. This is not correct, as erosion varies with degree, depth, and aerial distribution of soil exposure, all of which vary significantly with logging method.

7. Soil eroded due to logging and roads is routed to streams via a theoretical and untested model. While apparently logical, and thus providing hypothesis to be tested, its application is premature.

8. The example in the Guidelines produces a quantitative result through a series of seemingly logical steps. Even without varying these steps, equally "logical" quantitative results of tremendous variability can be generated. Application of these results could have significant impacts on land management decisions. If the decision is predicated on even relative accuracy of the model, then the decision may be more likely incorrect than correct.

Examination of the example is illuminating. Despite tractor logging with skid distances of up to 1.5 miles - uphill - on slopes which exceed 70 percent, erosion from roads is 16.5 times as great. Logging method is thus inconsequential within the model. I would suggest that an example taken directly from an actual timber sale or development plan would be far more helpful and provide a more useful means of assessing the models ability to reflect reality.

Also in the example, predicted erosion is greater than the arbitrary percent increase set as a limit. And this is without consideration of mass failures. In reality, a single debris avalanche from a road could easily deliver 10 to 100 times as much sediment to the example stream than was predicted from surface erosion from roads and logging combined. Interestingly, mass failures were ignored in the example.

Episodic mass failures occur naturally, and temporary acceleration of mass failure processes with development of road systems is a virtual certainty in many areas. However, if allowable increases in sediment increase such as "150 percent over natural" are actually used, exceedance is also a certainty. Methodologies predicting effects of sediment on Cutthroat trout and other salmonids would lead me to believe that mass failures, high sediment loads, and fish are incompatible. I submit that the natural history of the Northwest is evidence to the contrary. These interrelated problems deserve serious consideration on a policy level.

The question of how best to use the Guidelines Methodology is one
of whether it should be used to guide project development or
if professional judgement should be used. I know the Forest Service
will rely on both, but I would recommend that at any stage, heavy
emphasis be placed on the professional, not the model. The model
should be tested and refined prior to application to land manage-
ment plans.

More detailed technical discussion is attached as an Appendix.

Thank you again for the opportunity to become familiar with the
Guidelines and to comment upon them. I am hopeful that at least
some of these comments will prove useful as the Guidelines are
updated.

Sincerely,

Dale J. McGreer
Forest Hydrologist

DJM/mb
Attachments
cc: Mr. Ron Russell, Air Quality and Water Management, USFS, Missoul
      Montana
      Mr. J.C. McAdoo, Timberlands Manager, Potlatch Corporation,
      Lewiston, Idaho
      Ms. M.L. Franzese, Resource Planner, Potlatch Corporation,
      Lewiston, Idaho
      Mr. George Ice, NCASI
      Mr. Carl Deward, Resource Operations Manager, Potlatch Corporati
      Lewiston, Idaho - w/o appendices
      Mr. Richard Hallisy, Acquisition and Allocation Manager,
      Potlatch Corporation, Lewiston, Idaho - w/o appendices
      Mr. Keven Boling, Resource Coordination - Public Timber,
      Potlatch Corporation, Lewiston, Idaho - w/o appendices

Supplementary Detailed Discussion.

Point Number 1

A base erosion rate for the Batholith of 25 tons/mile^2/year is given. While I am confident that this value is indeed well founded, it would be more credible to in some way display the data supporting it rather than stating "unpublished".

Point Number 2

The discussion of mass failure processes within WRENS is excellent. Within the mass failure chapter, two distinctly separate means are provided for quantifying the predicted acceleration of failure occurrence following management. The first method is the quantitative rating system. It is totally unverified and unpublished other than in WRENS. The weighting of given factor coefficients, the weighting of factor coefficients relative to one another, and even the choice of factors used was strictly judgemental. The second method described simply requires prediction of the number and character of mass failures in undisturbed areas based on experience in similar previously developed areas. The Guidelines state, "The procedural techniques used should be based on the WRENS procedure and must be developed by the individual forests". Since there are many ways to use the WRENS procedures, I would suggest that more guidance is advisable.

The relationship displayed in Figure A, page 3 relates Average Natural Sediment Rate to Mass Erosion Hazard. It is a relationship without validation. One terribly obvious problem is that a curvilinear line has been developed from a single data point.

Dr. George Ice of the National Council of the Paper Industry for Air and Stream Improvement helped me look into the literature which could be applied to Figure A. He provides Figure A, attached. This data firmly indicates a lack of relationship between the Hazard Rating and Average Natural Sediment Rate. The sediment yield data used were obtained from the USDA Forest Service document "Erosion and Sedimentation Data Catalog of the Pacific Northwest". The Erosion Hazard Ratings were estimated based on our knowledge of the areas. (And since precipitation and slope dominate the hazards, it is difficult to be far from the mark.)

Dr. Ice notes:

    a. In <u>all</u> cases the slump-earthflow hazard was equal to or greater than the debris avalanche rating.

    b. Natural sediment yields varied from less than 10 tons/mile^2/year to nearly 1,800 tons/mile^2/year.

c. "The inability of the mass hazard rating to predict natural erosion rates is best demonstrated for three watersheds in the H.J. Andrews [Experimental Forest] which had the same hazard rating (51) but had monitored sediment yields of 3.07, 31.8, and 9.8 tons per mile squared per year."

It is also interesting to note the variance in the data collected at Silver Creek and at Horse Creek study watersheds in Idaho. What would the relationship look like if based upon Horse Creek as a single data point?

Point Number 4

Derivation of the land unit slope factor is arbitrary. Again, a curvilinear relationship has been developed from a single data point, and the end point estimated. I would add, however, that scaling between these points with a USLE slope-function (one of three used through the years and notably the most sensitive to slope) is preferable to using the USLE function itself. As briefly as possible, let me say that it may not be unreasonable that sediment delivery would double as slope increased by 50 percent from 50 to 75 percent slope. However, it does seem unreasonable that as slope decreases by 500 percent, from 50 percent to 10 percent slope, that only a 50 percent decrease in sediment delivery occurs.

Scaling of the relationship, given the lack of data, is clearly judgemental. There is little research which can be relied on. My own recent work (McGreer, 1981, attached) suggests that 1) erosion is not exponentially sensitive on steep slopes and 2) slope effects are interactive with other soil erosion and sediment delivery factors. In this experiment, I found that during the first year following disturbance of sections of skid trails 50 feet in length, increasing slope from 15 to 45 percent (40 percent in one case) resulted in increased delivered sediment from 0.28 to 0.30, 1.00 to 1.86, and 20.46 to 72.6 tons per acre for soil conditions of volcanic ash with litter layer partially retained, ash with the litter bladed away, and underlying sandy loam subsoil, respectively. Thus, the increases in erosion attributable to slope are far lower than would be predicted by the relationship given in the Guidelines.

Point Number 5

Equation 2 transforms "instream sediment values" to "on-site erosion" using an assumed delivery ratio of 0.33. This is appropriate for accelerated erosion but does not appear correct for natural erosion. Natural erosion and sediment delivery are equal values over long periods of time. Thus, I agree with the assumption of page 8: a basic assumption is made that the source of natural sediment is primarily stream channel erosion of banks and stored sediment. The source of supply of this eroded material is assumed to be from natural mass slope erosion processes. (Natural surface erosion and delivery is expected to be insignificant from

undisturbed forested watersheds.) Rather than Equation 2 as
given:

$$\frac{(2.5 \times 75) - 75)}{0.33} = 341 \text{ T/Mi.}^2\text{/Yr.} \quad \text{on-site erosion,}$$

I believe the equation is correctly simplified to:

$$\frac{2.5 \times 25}{0.33} = 189 \text{ T/Mi.}^2\text{/Yr.} \quad \text{on-site erosion following logging}$$

As a check, 189 x 0.33 = 56.7 T/Mi.^{2}/Yr.

$$\frac{56.7 \text{ T/Mi.}^2\text{/Yr.}}{25 \text{ T/Mi.}^2\text{/Yr.}} = 2.27$$

This corresponds well with 2.5 x natural expected, as discussed
on page 19 of the Guidelines.

Point Number 7

Table 6 assumes a 1 to 1 relationship between percent bare soil
and amount of erosion produced. This is not appropriate for
several reasons. First, soil erosion varies dramatically with soil
characteristics such as texture, structure, permeability, and
organic content. It thus varies with horizon and depth. I
believe there is literature showing that there is proportionately
more deep soil disturbance associated with tractor logging than
with cable systems. Second, it is often discussed that uphill
cable systems disperse water as opposed to concentrating it as
do downhill ground skidding systems. This is more significant
when one thinks of sediment delivery processes of overland flow
down tractor trails to landings and roads as opposed to little
or no overland flow down discontinuous areas of cable disturbance –
which also is concentrated near landings at (usually) the top of
the unit. But there is no accounting of these factors in the
coefficient. I would, therefore, suggest searching for references
which would allow coefficient adjustment for these factors.
Intuitively, downward adjustments of 50 to 75 percent for cable
logging do not seem unreasonable.

The Example

In studying the example, I found it useful to go through it by
substituting coefficients and base values derived from the sources
I have mentioned – mainly Horse Creek. In so doing, additional
aspects of the model which I feel need adjustment became apparent
and are noted.

In order to allow comparison with the original example, I did not
change units, road locations, or logging methods.
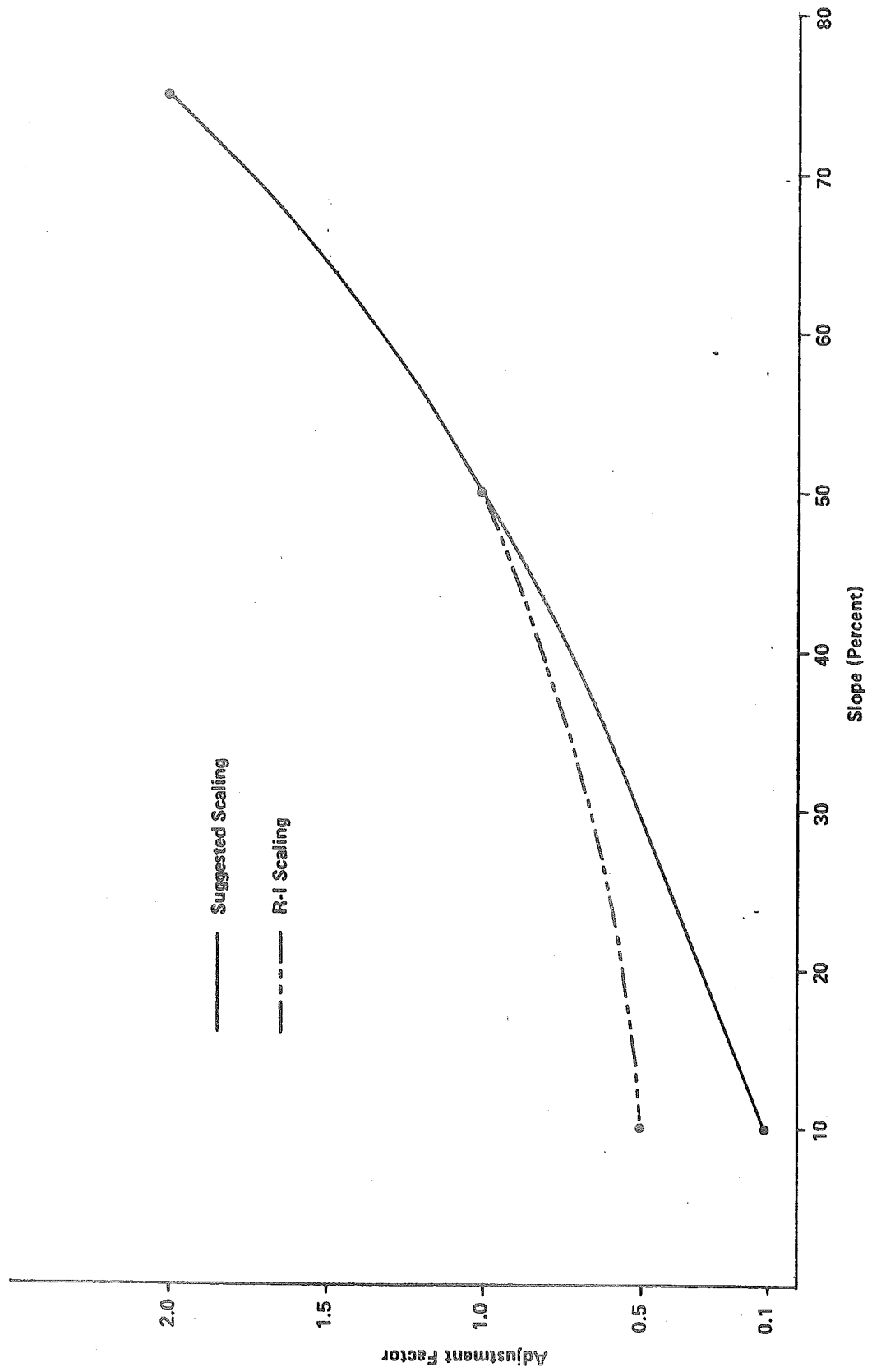
The revised example follows.

3

Figure B

Adjustment Factor

Slope (Percent)

Suggested Scaling

R-I Scaling

Table 7x - Data

Land Unit #	(1)[**] Geologic Erosion Factor	(2)[**] Mass Erosion Hazard Rating	(3) Average Slope (%)	(4)[*] Land Unit Slope Factor	(5)[*] Slope Sediment Delivery Ratio
1	0.31	--	70	1.70	.05
2	0.31	--	25	0.40	.03
3	0.31	--	40	1.72	.04

[*] Coefficient change
[**]Procedural and coefficient change

(1) $\dfrac{\text{Horse Creek Yield}}{\text{Guidelines Base Yield}} = \dfrac{10.6 \text{ tons/mi.}^2/\text{yr.}}{33.75 \text{ tons/mi.}^2/\text{yr.}} = 0.31$

(2) No adjustment used due to evidence that no relationship exists.

(3) As given.

(4) Per Revised Function, Figure B

(5) Delivery Ratios derived directly from Figure IV.22 of the Guidelines. Note that the delivery ratios I have used are far lower than those used in the Guidelines example.

In studying this, I first assumed the most extreme conditions that I could imagine, yet even then could only maximize delivery for Unit #1 to 40% (texture: 35% fines. Available H_2O: 2" R/O per hour and 100' slope length yields 0.005. Site specific maximized at 100 (for no rational reason), 100 ft. delivery distance, slope shape = 0 (which it cannot universally be) and ground cover of a very low 10%.

To arrive at the delivery factors used in the revised example, I used the following factors for Unit #1, which albeit for lower, continue to be conservatively based:

Texture:	25% fines
Available H_2O:	.0046 (100' length, 2" R.O.)
Site specific:	not used
Slope gradient:	70%
Surface roughness:	1 (smooth)
Delivery distance:	100' (short, and notice that delivery distance and slope length in available H_2O are compensating
Slope shape:	1 (efficient)
% ground cover:	30% (lower than normal even after burning in most cases)

Table 8x - Natural Sediment Yield

Land Unit #	(1) Land Type Area (mi.^{2})	(2)* Mass Erosion Adjustment Factor	(3) Ave. Natural Sediment Rate (T/Mi.^{2}/Yr.)	(4) Land Unit Natural Sediment (T/Yr.)
1	6.51	--	10.6	69.0
2	4.62	--	10.6	49.0
3	3.87	--	10.6	41.0
	15.00			159.0

Ave. Natural Sediment Rate = 10.6 T/Mi.^{2}/Yr.

*Procedural and coefficient change

(2) Note that if Mass Erosion adjustment factors based on WRENS were used, the natural rates would be lower: Est. Horse Creek Ratings = 25 for debris avalanches and 39 for slump-earth flows.

i.e., for Unit #3: $\dfrac{14}{40}$ = 0.35

Table 9x - Sediment Yield Under Present Management

Land Unit #	(1) Adjusted Fire Erosion Rate (T/Mi.^{2}/Yr.)	(2) Disturbed Area (mi.^{2})	(3) – Same –	(4) Fire Intensity Factor	(5) Total Fire Erosion (T/Yr.)	(6) Delive Sedime (T/Yr.
1	170	0.94	––	0.60	94.0	4.7
2	170	0.90	––	0.43	19.7	0.6
3	170	0.0	––	––	––	––
		1.84				5.

Unit Area Basis: $\dfrac{5.3 \text{ T/Yr.}}{15 \text{ mi.}^2}$ = 0.35 T/mi.^{2}/Yr.

(1)   550 T/mi.^{2}/Yr. x 0.31

Table 10x - Sediment Yield Under Present Management for a 5-Year Period

(1) Year	(2) Natural Sediment Yield $(T/Mi.^2/Yr.)$	(3) Sediment Yield due to Fire $(T/Mi.^2/Yr.)$	(4) Present Cond. Total Yield $(T/Mi.^2/Yr.)$	(5) Increase Over Natural (%)
1	10.6	0.35	10.95	3.0
2	10.6	0.08	10.68	0.8
3	10.6	0.01	10.61	--
4	10.6	0.0	10.60	--
5	10.6	0.0	10.60	--

(3) Yields adjusted through time in the same manner as does the Guidelines example.

Table 11x - Sediment Yield under Proposed Management - Roads

Land Unit #	(1) Basic Road Erosion Rate (T/Mi.^{2}/Yr.)	Geologic Erosion Factor	(5) Disturbed Area (Mi.^{2})	(6) Mitigation Factor
1	67,500	.31	.032	0.60
2	67,500	.31	.026	0.58
3	67,500	.31	.010	0.58

(7) Total Road Erosion (T/Yr.)	(8)* Road Sediment Delivery Ratios	(9) Delivered Sediment
401.8	0.35	140.6
315.6	0.20	63.1
121.4	0.25	30.4
		234.1

*It is not reasonable to assume that delivery ratios for logging are the same as those for roads (as does the Guidelines Example).

I used the following in Figure IV.22:

25% fines
.10 H$_2$O available
Site specific not used
Slope gradient = sideslope gradients as given
Surface roughness = 0
Delivery distance = 20 feet
Slope shape = 1
% ground cover, year 1 = 10%

LT#1 = 0.7/2 = 0.35
LT#2 = 0.4/2 = 0.20
LT#3 = 0.5/2 = 0.25

I also divided the composite by 2, to adjust for those portions of roads which deliver sediment much less efficiently, i.e., road fills, discharge from isolated relief culverts, etc.

Table 12x - Data Needed to Calculate Sediment Yield under Proposed
Management - Logging

Land Unit #	Geologic Erosion Factor (1)	Timber Sale Area (2)	Logging System Factor (4)	Disturbed Area (mi.^{2})	Basic Logging Erosion Rate (T/Mi.^{2}/Yr.) (5)*	Total Logging Erosion (T/Yr.) (6)	Delivered Sediment (T/Yr.) (7)
1	0.31	B	1.00	0.03	189	1.8	0.1
2	0.31	A	0.71	0.26	189	10.8	0.3
3	0.31	B	1.00	0.64	189	37.5	1.5
							1.9

Per Unit Basis: $\dfrac{1.9 \ T/Yr.}{.5 \ Mi.^2} = 0.13 \ T/Mi.^2/Yr.$

(5) Basic logging erosion rates are derived from equation 2,

revised:

$$\frac{2.5 \times 25}{0.33} = 189 \ T/Mi.^2/Yr.$$

Table 13x - Sediment Yield under Proposed Management for a 5-Year Period

Year	(1) Natural Sediment Yield $(T/Mi.^2/Yr.)$	(2) Mgmt. - Induced Yield $(T/Mi.^2/Yr.)$ Roads	Logging	Fire	(3) Total Yield $(T/Mi.^2/Yr.)$	(4) Increase Over Natural (%)
1	10.6	15.61	0.13	0.35	26.69	152
2	10.6	4.16	0.07	0.08	14.92	41
3	10.6	1.17	0.05	0.02	11.84	12
4	10.6	1.16	0.03	0.00	11.80	11
5	10.6	1.17	0.02	0.00	11.79	11

Table 14x - Summary Comparison of Guidelines Example to Revised Example

	Guidelines Example	Revised Example
Natural Yield (T/Mi.^{2}/Yr.)	15.5	10.6
First Year Sediment Yield Increase (%)	195.0	152.0
5-Year Average Sediment Yield Increase (%)	57.0	45.0
First Year Sediment Yield Increase (T/Mi.^{2}/Yr.)	30.3	16.1
5-Year Sediment Yield Increase (T/Mi.^{2}/Yr.)	44.6	24.0

Table 14x - Summary Comparison of Guidelines Example to Revised Example

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5-Year Average Sediment Yield Increase (%)	57.0	45.0
First Year Sediment Yield Increase (T/Mi.^{2}/Yr.)	30.3	16.1
5-Year Sediment Yield Increase (T/Mi.^{2}/Yr.)	44.6	24.0

Skid Trail Erosion Tests - First-Year Results
July, 1981
Dale J. McGreer
Forest Hydrologist

ABSTRACT

Seven plots were established near Headquarters to determine the erosivity of the "ash cap" topsoil and underlying sandy loam subsoil. Plots 50 feet ± long and 10 + feet wide were established with a D-6 cat. Three soil conditions on 15 and 45 percent slope were tested: 1) ash with a disturbed litter layer, 2) ash with the litter bladed away, and 3) the underlying subsoil. A seventh plot was formed on a 50 percent slope by covering exposed subsoil with slash. Total quantity of erosion was trapped from each plot.

TOTAL CUMULATIVE FIRST-YEAR EROSION

Plot	Ash w/ litter 15% Slope	Ash w/ litter 45% Slope	Ash 15% Slope	Ash 45% Slope	Subsoil 15% Slope	Subsoil w/slash 50% Slope	Subsoil 40% Slope
Pounds	6.5	7.5	23.8	42.7	645	29.5	2,474

These results show that ash topsoils are resistant to erosion but that exposure of underlying subsoils results in erosion rates severe enough to reduce long term soils productivity and to create stream sedimentation. Organic litter or slash are shown to effectively prevent erosion.

Recommendations justified by the study include 1) avoiding bladed skid trails, 2) minimizing width and depth of necessary trails, and 3) limbing and topping on skid trails.

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INTRODUCTION

Erosion has been of concern to Potlatch since at least 1953,
when the first tests of seeding and waterbarring were
conducted by the company.[1] Additional trials have been
conducted since that time, and controls implemented as
standard practices.

Today, approximately $250,000 per year is allocated by
Potlatch for erosion control on our fee ownership. ($0.75/MBF
as contractual allowance plus $0.40/MBF fee harvest paid to
the C-PTPA and other fire control districts.) Given contin-
uing legislative and administrative pressure for improved
control of erosion, the need to preserve the productivity of
our timberlands, and the high costs of doing so, erosion must
be controlled with the most cost-effective means available.

This study was initiated to determine the relative erosivity
of major soil types and soil horizons, and to identify
efficient means of reducing skid trail erosion rates. First-
year's results are reported.

The study was conducted to the northeast of Headquarters in
the NE¼ of Section 15, T38N, R5E. Slopes are short, but
steep; up to 65%. The area has been selectively logged with
ground machinery through the years. Soils have developed from
a layer of fine sandy loam alluvium which typically ranges
from 12 to 48 inches in depth. This layer overlies coarse
textured decomposed granite. The alluvial "subsoil" is capped
with fine textured Mt. Mazama volcanic ash, as is most of
Potlatch's ownership. Ash depths in the study area generally
vary from 10 to 16 inches. Undisturbed bulk density of the
ash averages 0.75 gms. cm^{-3}. Undisturbed bulk density of the
underlying alluvial subsoil averages 1.1 gms. cm^{-3}.

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[1] A "Review of Erosion Control Practices" was presented by
Royce Cox to a Foremen's Council meeting in December of 1953.
Participants in these studies included Charlie McCollister,
Vern Robinson, Charles Sutherland, and Bob Tondevold, Sr.

LITERATURE REVIEW

Research on erosion associated with forest operations is extensive. However, surprisingly little is directly applicable to the combination of extensive ground skidding and fine volcanic ash topsoils unique to Northern Idaho, parts of Eastern Washington, and Northwestern Montana.

Megahan[2] (1972), Studied erosion following road construction and jammer logging in the granitic soils of South-Central Idaho. He reports some of the largest increases in erosion following logging that appear within the literature: An increase due to roads of 770 times natural, and 220 times natural due to logging. While the erosion he observed was unquestionably high, the results must be applied cautiously due to the unusually erosive nature of the area studied: Shallow decomposed granite overlying bedrock, slopes averaging 70%, stream channel gradients averaging 65%, and side-cast road construction with no erosion control until after logging in the second year.

Despite the specific circumstances to which Megahan's results are applicable, his results are often used (primarily be the Forest Service) to evaluate management in areas with quite different physical characteristics.

The relative erosivity of various soil parent materials (rock types) native to Idaho have not been systematically studied. However, using Megahan's work as a benchmark, Rosquist (1980)[3] reports estimates of relative erosivity.

Soil Class	Relative Erosivity
Granitics	1.00
Lucustrine Deposits	1.22
Glacial Tills	0.56
Belt Series Metamorphics	0.27

Several parent material types native to Northern Idaho are not included above and would likely broaden the range of relative erosivity reported.

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[2]Megahan, W.F. and W.J. Kidd. 1972. Effects of logging roads on sediment production rates in the Idaho Batholith. Intermountain Forest and Range Experiment Station Res. Pap. INT-123. USDA Forest Service, Ogden, Utah.

[3]Rosquist, A.E. 1980. Lolo National Forest plan draft EIS, Appendix B-7f: Hydrology - sediment yield. U.S. Forest Service, Lolo National Forest, Missoula, Montana.

Even if in reality the range is much broader, it can be shown to be quite narrow compared to other factors influencing the erosion process. The Universal Soil Loss Equation (USLE), (EPA, 1980)[4], originally developed for tilled agricultural soils on gentle slopes, has since been modified for silvicultural applications, and illustrates this point. Although the accuracy of the USLE applied to silvicultural applications is disputable, it does provide a reasonable means of examining the relative importance of various factors influencing the erosion process. It also provides a means of identifying which factors can be manipulated to most effectively control erosion.

In estimating the amount of erosion to be expected from an area, the equation considers long-term average rainfall intensity and duration, soil characteristics, slope steepness, slope length, and vegetation management factors. It is useful to look at the range of values associated with each of these factors: The rainfall factor varies from about 10 to 550 across the U.S., but only from 20 to 40 (100%) throughout all of Idaho. The soil properties factor varies from .02 to .54 (2600%). Slope length and steepness variables interact and are best evaluated by looking at the following table, where both variables are increased by a factor of 25.

Slope Steepness	Slope Length		Factor Increase
	40'	1000'	
	Factor Values (dimensionless)		
2	2.58	6.79	2.63
50	11.04	55.19	5.00
Factor Increase	4.28	8.13	

Thus it can be seen that by ranging slope steepness and length from 2% and 40 feet to 50% and 1000 feet, the factor value changes by 2,039% (2.58 to 55.19). The final factor, the vegetation management factor, turns out to be most significant: It realistically varies through a range of 0.01 to 130 (12,990%) for mulched soils to bulldozer scraped soils.

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[4]U.S. Environmental Protection Agency 1980. An approach to water resources evaluation of non-point silvicultural sources. Environmental Research Laboratory, Athens, Georgia.

The equation reveals that soil properties and properties of vegetation (soil cover) have the greatest effect on the erosion process. (Note that the soil factor is indeed controllable, as it depends upon permeability, texture, structure, and organic matter - properties which change with depth in a given soil and which can be altered by management.)

The equation thus suggests that in logging, exposure of less permeable and poorly structured sandy subsoils low in organic matter would result in more erosion than where permeable volcanic ash topsoils high in organic matter are left in place. This hypothesis was tested in the experiment.

METHODS

Seven experimental plots were established to determine the relative erosivity of the "ash cap" and the underlying alluvial soil horizon. In all but one case, (plot #2), plots were established on old skid trails. A D-6 cat was used to blade into the soil horizon desired for each test. Waterbars were placed above and below each test section.

The experimental design called for plots 50 feet long, and at 10 and 40 percent slope on each of three soil conditions: 1) ash with a disturbed, but remnant litter layer present (ash with litter), 2) ash with the litter layer deliberately bladed away (ash without litter), and 3) alluvial subsoil. A seventh plot was also created in the alluvial subsoil by placing slash on a plot of 50 percent slope. Plots were also planned for the underlying decomposed granite. However, the overlying ash and alluvium was so deep that the decomposed granite could not be exposed without major and unrepresentative excavation. Exact plot dimensions are given in Table 1.
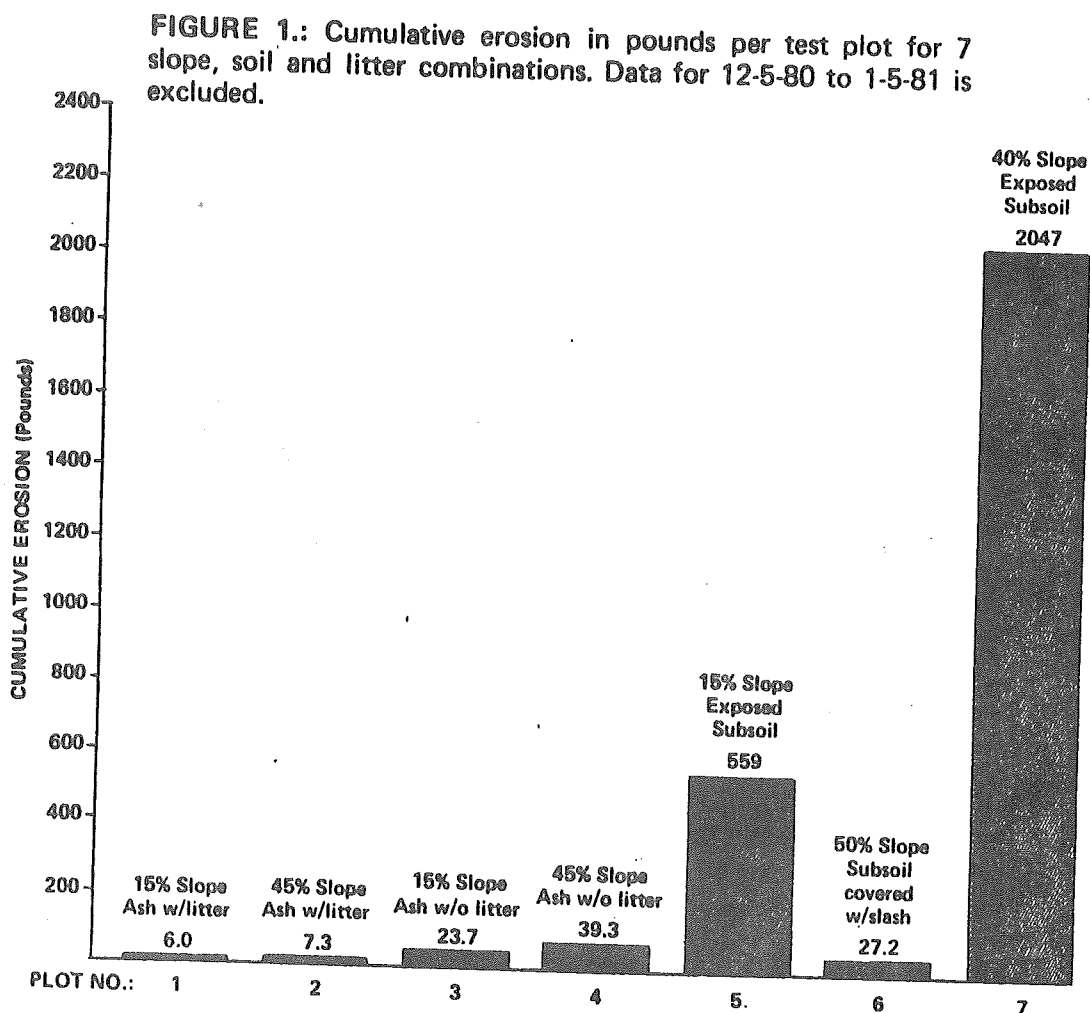
TABLE 1
Experimental Plot Dimensions

Plot #	Length (feet)	Width (feet)	Slope (%)
1	50	10	15
2	50	11	45
3	47	11	15
4	50	10	45
5	53	13*	15
6	54	11	50
7	53	14*	40

*These wider widths are due to the widths of backslopes which contribute erodible surface within test plots on these steep slopes.

Total runoff and eroded sediments are channeled through plywood
flumes into plywood sediment traps placed at the lower end
of each plot. Total quantity of erosion is periodically
determined by shoveling the trapped sediment into plastic
buckets which are weighed in the field with a hanging scale.
Samples are collected for laboratory conversion to a dry
weight basis.

RESULTS

First-year results for the period of June 25, 1980, through
June 23, 1981, show wide variation in cumulative erosion among
the plots due to the effects of slope and soil condition.
Figure 1 illustrates total first-year erosion. (Note that
the figure excludes data from 12/5/80 to 1/5/81 due to flume
failures at plots 5 and 6.) Radical differences in the
amount of erosion per plot are obvious.

FIGURE 1.: Cumulative erosion in pounds per test plot for 7
slope, soil and litter combinations. Data for 12-5-80 to 1-5-81 is
excluded.

Effects of soils, litter and slash have been far more significant than those of slope: On 15% slopes, total erosion was least in the ash-with-litter test: 6.0 pounds. Erosion increased by a factor of 3.9 to 23.5 pounds for the ash-without litter test, and by a factor of 93 to 559 pounds on the exposed subsoil test.

On 45% slopes (40% on number 7), erosion increased from 7.3 pounds on the ash-with-litter plot to 39.3 pounds (a factor of 5.4) and to 2,047 pounds (a factor of 210) on the ash-without-litter and exposed subsoil tests, respectively.

Slope effects were far less pronounced. Increasing slope from 15% to 45% (40% for number 7) increased erosion by factors of 1.2, 1.7, and 3.7 in the ash-with-litter, ash-without-litter and exposed subsoil plots, respectively. These changes are obviously far smaller than those observed due to soil exposure.

Placing slash on the plot with exposed subsoil and 50% slope resulted in over 75 times less erosion: 27.2 pounds vs. 2,047 pounds for plots 6 and 7, respectively.

In Table 2, pounds of erosion per plot are converted to tons per acre equivalent and to area inches. In all of the test plots where the ash soil horizon was not removed, total erosion is relatively low. Test plot number 4 (45% slope) produced the most erosion of any of these plots: Only 1.86 tons per acre equivalent (i.e., 1 acre of 50-foot long, 45% slope sections of trail), or 0.022 area inches.*

In contrast, 72.6 tons per acre equivalent (0.58 area inches) were produced from test plot 7 with exposed subsoils. Even on gentle (15%) slopes, the exposed subsoils of Plot 5 produced 20.5 tons of erosion per acre equivalent: 0.16 area inches.

As a comparison, four tons per acre of soil loss on the agricultural soils of the Palouse Prairie is thought to be acceptable for maintaining long-term productivity. For the test plots with ash horizons, soil loss rates were far lower even during the first year following disturbance, and are already approaching a zero rate. These rates, amortized through a rotation, are clearly low enough to maintain productivity. (For example, 1.86 tons per acre-year for plot 4 over 40 years yields an average of only 0.05 tons per acre-year.)

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*Area inches assumes even distribution of erosion throughout the area (plot), which in reality is seldom, if ever the case. However, the measure is useful as an easy to visualize unit.

Where subsoils were exposed, however, productivity may well
be reduced. First, whenever the topsoil is removed, productivity
will decrease. Secondly, even the first year's quantity of
erosion from Plot 7 (40% slope) equals an average of 1.82 tons
per acre on a 40-year entry basis. On the 15% slope of Plot 5,
although erosion rates are lower, they are severe enough that
long-term productivity will likely be reduced, aside from the
initial effects of removing the ash topsoil. In contrast to
the plots with ash, erosion rates, while decreasing, can be
expected to remain high for at least the second year. Time
trends of erosion are illustrated in Figures 2, 3, and 4.

FIGURE 2.: Cumulative erosion in pounds per test plot for 5 slope, soil and litter
combinations. Precipitation is shown on the right-hand ordinate. Data for 12-5-80 to
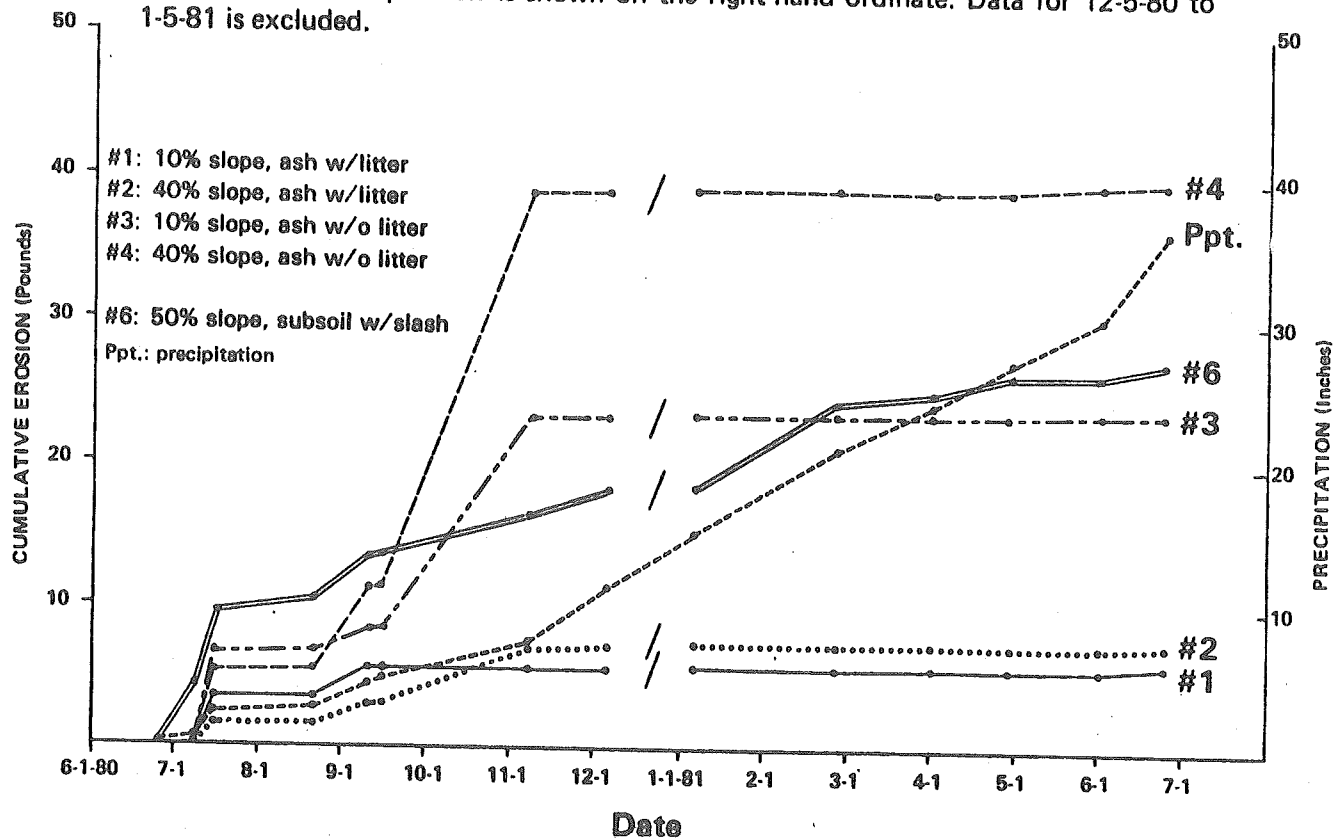1-5-81 is excluded.

#1: 10% slope, ash w/litter
#2: 40% slope, ash w/litter
#3: 10% slope, ash w/o litter
#4: 40% slope, ash w/o litter

#6: 50% slope, subsoil w/slash

Ppt.: precipitation

FIGURE 3.: Cumulative erosion in pounds per test plot for 3 slope, soil and litter combinations. Precipitation is shown on the right-hand ordinate. Data for 12-5-80 to 1-5-81 is excluded.

#5: 10% slope, subsoil
#6: 50% slope, with slash
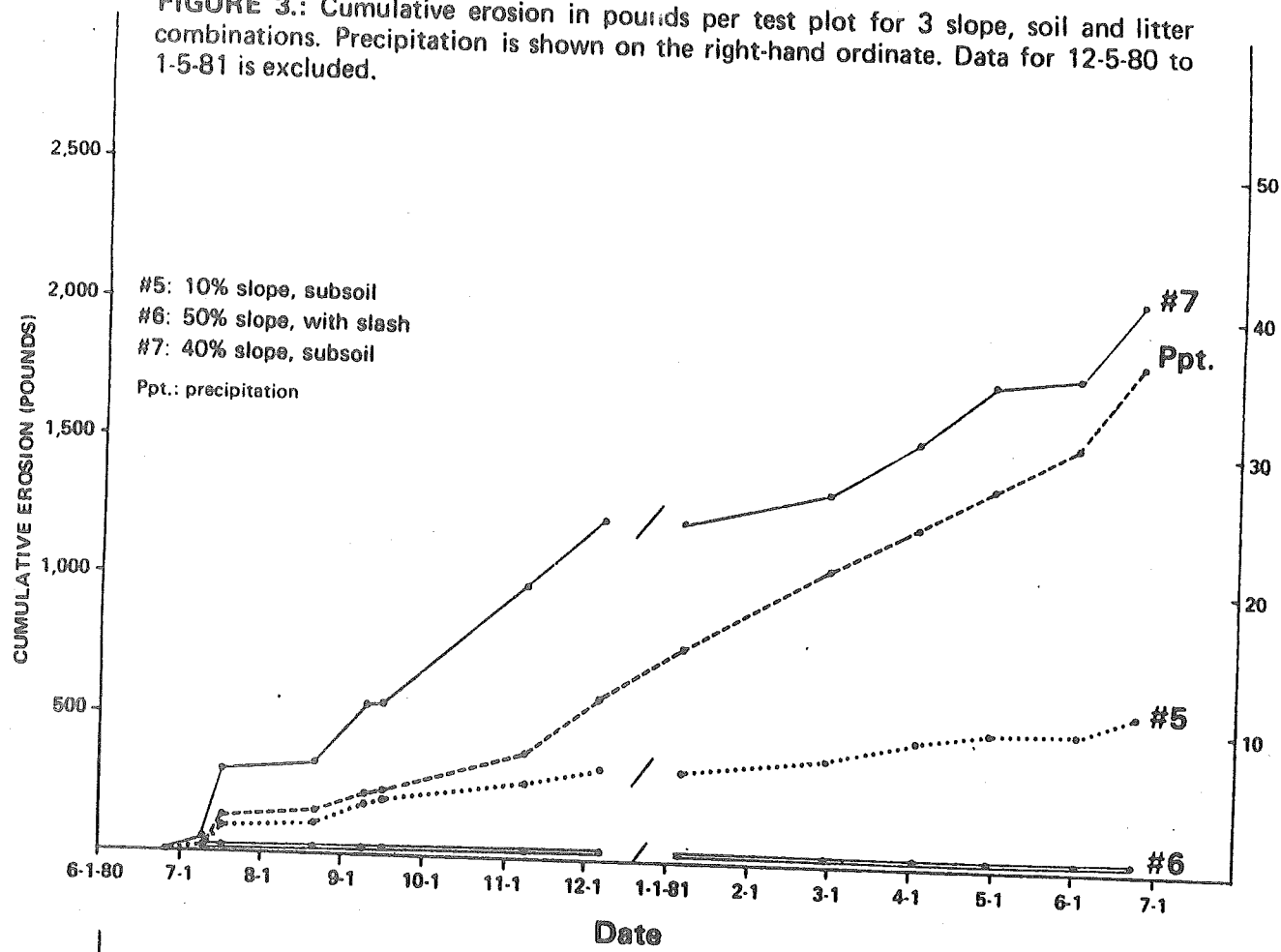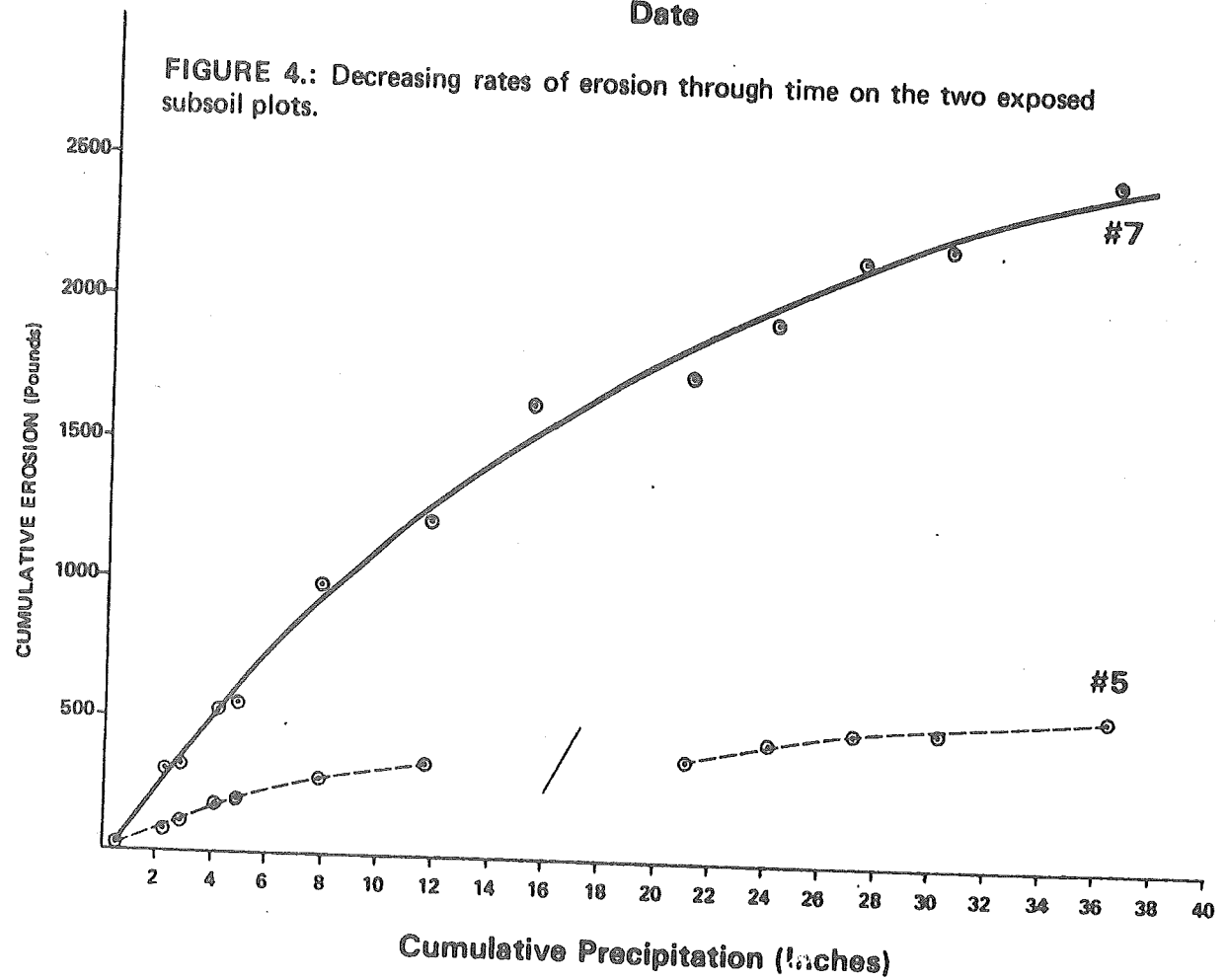#7: 40% slope, subsoil

Ppt.: precipitation

FIGURE 4.: Decreasing rates of erosion through time on the two exposed subsoil plots.

Figures 2 and 3 indicate that rates of erosion on Plots 1, 2, 3, 4, and 6 are decreasing rapidly and are approaching rates too low to measure on a small test plot basis. Note that Plots 1, 2, 3, and 4 are tests with the ash layer intact, and that Plot #6 is covered with slash.

Trends for Plots 5 and 7 (with exposed subsoils) are not so obvious, but Figure 4 reveals that their erosion rates are in fact decreasing. The primary reason appears to be due to revegetation of the test plots.

TABLE 2. Total Cumulative First-Year Erosion: 6-25-80 to 6-22-81.[1]

Plot No.	1	2	3	4	5	6	7
Pounds	6.5	7.5	23.8	42.7	646.7	29.5	2,474
Pounds per acre equivalent	566	594	2,005	3,720	40,930	2,169	145,239
Tons per acre equivalent	0.28	0.30	1.00	1.86	20.46	1.08	72.6
Area inches	0.003[2]	0.004	0.012	0.022	0.164[3]	0.013	0.583

[1] Data for plots 5 and 6 from 12-5-80 to 1-5-81 were estimated through correlation to plot #7.
[2] Using an average bulk density of 0.75 gms cm^{-3} for plots 1 through 4.
[3] Using an average bulk density of 1.1 gms cm^{-3} for plots 5 through 7.

Plots 1, 2, 3, and 4, with least disturbance, are revegetating most rapidly, thus accounting for their rapid decrease in rate of erosion.

CONCLUSIONS

1. Skid trails which do not entirely remove the forest litter layer are not subject to significant erosion.

2. Exposure of volcanic ash topsoils increases erosion rates, but these rates are acceptable (assuming proper control of runoff through appropriate waterbarring).

3. Exposure of subsoils results in rates of erosion which likely reduce long-term soils productivity, even beyond that created by initial removal of productive topsoils, and even where conscientiously waterbarred.

4. Slash effectively controls skid trail erosion. Furthermore, control is immediate and effective even during the first year following disturbance - the interval when a major portion, if not the majority, of total erosion occurs.

5. Erosion rates on exposed subsoils are high even on gentle slopes. Erosion rates on volcanic ash topsoils are low even where slopes are steep.

RECOMMENDATIONS

1. Bladed skid trails should be avoided, to the extent that logging and silvicultural considerations allow, in order to:

   a. minimize site productivity losses
   b. minimize the need for costly waterbarring and other erosion control
   c. minimize offsite damage (i.e., stream sedimentation)

2. Where blading is necessary, width and depth should be minimized.

3. Trees should be topped and limbed on skid trails to the extent feasible. This recommendation becomes especially important where runoff from major bladed trails could be expected to reach stream channels.